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(21) Application No.	Patent application no. 2000-216868	(71) Applicant	000004112 Nikon Corp. 3-2-3 Marunouchi, Chiyoda-ku, Tokyo
(22) Date of Application	July 18, 2000	(72) Inventor	Tsuneyuki Hagiwara c/o Nikon Corp. 3-2-3 Marunouchi, Chiyoda-ku, Tokyo
		(74) Agent	Atsushi Tateishi, patent attorney
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(54) Title of the invention: Aerial image measurement method, image forming properties measurement method, Aerial image measurement unit, and exposure apparatus

(57) Abstract

Purpose: To provide a measurement method which is capable of measuring an aerial image with a sufficient accuracy.

Configuration: On a slit plate 90 of an aerial image measurement unit 59, a slit 22 is formed extending in the Y-axis direction of which the width in the measurement direction (X-axis direction) is equal to or below (wavelength λ/numerical aperture N.A. of the projection optical system). Therefore, in a state where a predetermined pattern PM is illuminated with illumination light IL to form an aerial image of the pattern on an image plane via the projection optical system PL, and when the slit plate 90 is scanned in the X-axis direction with respect to the aerial image, the light having passed through the slit 22 during the scanning is photo-electrically converted with a photoelectric conversion element 24, and thus the photoelectric conversion signal (signal corresponding to the light intensity of an aerial image) is output. Further, based on the photoelectric conversion signal, the control unit measures the light intensity distribution corresponding to the aerial image. In this case, the width of slit 22 is equal to or below (λ/N.A.), and hence an aerial image with a sufficiently high accuracy for practical usage can be measured.

Scope of Patent Claims

Claim 1

An aerial image measurement method to measure an aerial image of a predetermined pattern formed by a projection optical system, said measurement method including: illuminating said pattern with illumination light and forming an aerial image of said pattern on an image plane via said projection optical system; and scanning a slit plate, which has at least one slit extending in a first direction within a two-dimensional plane perpendicular to an optical axis of said projection optical system of which a width perpendicular to said first direction within said two-dimensional plane serving as a second direction is set in consideration of a wavelength λ of said illumination light, in said second direction within a surface close to said image plane parallel to said two-dimensional plane, and photo-electrically converting said illumination light having passed through said slit and obtaining a photoelectric conversion signal which corresponds to an intensity of said illumination light having passed through said slit.

Claim 2

An aerial image measurement method to measure an aerial image of a predetermined pattern formed by a projection optical system, said measurement method including: illuminating said pattern with illumination light and forming an aerial image of said pattern on an image plane via said projection optical system; and scanning a slit plate, which has at least one slit extending in a first direction within a two-dimensional plane perpendicular to an optical axis of said projection optical system of which a width perpendicular to said first direction within said two-dimensional plane serving as a second direction is set in consideration of a numerical aperture N.A. of said projection optical system, in said second direction within a surface close to said image plane parallel to said two-dimensional plane, and photo-electrically converting said illumination light having passed through said slit and obtaining a photoelectric conversion signal which corresponds to an intensity of said illumination light having passed through said slit.

Claim 3

The aerial image measurement method according to claim 1 or 2, wherein said width of said slit in said second direction is greater than zero, and equal to or below said wavelength λ of said illumination light divided by said numerical aperture N.A. of said projection optical system (λ/N.A.).

Claim 4

The aerial image measurement method according to claim 3, wherein said width of said slit in said second direction is equal to or below said (λ/N.A.) multiplied by 0.8.

Claim 5

The aerial image measurement method according to claim 1 or 2, wherein said width of said slit in said second direction is half a minimum pitch multiplied by an odd number, said pitch being a pitch of a line and space pattern in a limit of resolution set by illumination conditions including properties of said illumination light and the type of said pattern.

Claim 6

The aerial image measurement method according to claim 1 or 2, wherein when a wavelength of said illumination light is expressed as λ and a numerical aperture of said projection optical system is expressed as N.A., said width of said slit in said second direction is set as $\{\lambda/(2N.A.)\}$ multiplied by an odd number.

Claim 7

The aerial image measurement method according to any one of claims 1 to 6, said measurement method further including: obtaining a spatial frequency distribution by performing a Fourier Transform on said photoelectric conversion signal; converting said spatial frequency distribution into a spectrum distribution of its original aerial image by dividing said spatial frequency distribution with a frequency spectrum of said slit that is already known; and recovering said original aerial image by performing an inverse Fourier Transform on said spectrum distribution.

Claim 8

An image forming properties measurement method to measure image forming properties of a projection optical system, said measurement method including: illuminating a predetermined pattern with illumination light and forming an aerial image of said pattern on an image plane via said projection optical system; scanning a slit plate, which has at least one slit with a predetermined slit width extending in a first direction within a two-dimensional plane perpendicular to an optical axis of said projection optical system, within a surface close to said image plane parallel to said two-dimensional plane in a second direction which is perpendicular to said first direction, and photo-electrically converting said illumination light having passed through said slit and obtaining a photoelectric conversion signal which corresponds to an intensity of said illumination light having passed through said slit; and obtaining image forming properties of said projection optical system performing said photoelectric conversion signal by said predetermined treatment.

Claim 9

The image forming properties measurement method according to claim 8, wherein said pattern consists of a line and space pattern that has a periodicity in a direction corresponding to said second direction, detection of said photoelectric conversion signal is repeated a plurality of times while changing a position of said slit plate in a direction of said optical axis, Fourier Transformation is performed

respectively on a plurality of photoelectric conversion signals obtained by repeatedly performing said predetermined treatment in said detection; a contrast is obtained which is an amplitude ratio of a first order frequency component and a zero order frequency component of respective signals; and a position of said optical axis is detected which corresponds to a photoelectric conversion signal with said contrast maximized, to thereby detect a best focus position of a projection optical system.

Claim 10

The image forming properties measurement method according to claim 9, wherein said method further includes detecting an image plane shape of said projection optical system by repeatedly performing detection of said best focus position on a plurality of points distanced differently from an optical axis of said projection optical system.

Claim 11

The image forming properties measurement method according to claim 9, said measurement method further including: performing detection of said best focus position along an optical axis of said projection optical system repeatedly on a plurality of line and space patterns having a different pitch, and obtaining a spherical aberration of said projection optical system based on a difference of said best focus position corresponding to each of said patterns.

Claim 12

The image forming properties measurement method according to claim 8, wherein said pattern includes at least one rectangular pattern where a width in said second direction is larger than a width of said slit in said second direction; forming of said aerial image and detection of said photoelectric conversion signal are repeatedly performed on an aerial image of said pattern projected at different positions within an image field of said projection optical system, and a phase detection is performed based on a plurality of photoelectric conversion signals obtained by said predetermined repeated treatment, a position of an aerial image individually corresponding to said plurality of photoelectric conversion signals is respectively calculated based on a result of said phase detection, and at least one of a distortion and a magnification of said projection optical system is obtained based on said calculation results.

Clam 13

The image forming properties measurement method according to claim 8, wherein said pattern includes at least one rectangular pattern where a width in said second direction is larger than a width of said slit in said second direction; forming of said aerial image and detection of said photoelectric conversion signal are repeatedly performed on an aerial image of said pattern projected at different positions within an image field of said projection optical system, and a phase detection is performed

based on an intersection point of each of a plurality of photoelectric conversion signals obtained by said predetermined repeated treatment and a predetermined slice level, a position of an aerial image individually corresponding to said plurality of photoelectric conversion signals is respectively calculated, and at least one of a distortion and a magnification of said projection optical system is obtained based on said calculation results.

Clam 14

The image forming properties measurement method according to claim 8, wherein said pattern is a rectangular shape as a whole, and consists of a line and space pattern having a periodicity in said first direction.

Claim 15

The image forming properties measurement method according to claim 14, wherein forming of said aerial image and detection of said photoelectric conversion signal are repeatedly performed on an aerial image of said pattern projected at different positions within an image field of said projection optical system, and based on an intersection point of each of a plurality of photoelectric conversion signals obtained by said predetermined repeated treatment and a predetermined slice level, a position of an aerial image individually corresponding to said plurality of photoelectric conversion signals is respectively calculated, and at least one of a distortion and a magnification of said projection optical system is obtained based on said calculation results.

Claim 16

The image forming properties measurement method according to claim 8, wherein said pattern consists of a line and space pattern having a periodicity in a direction corresponding to said second direction, and, an abnormal line width value of each line pattern is calculated based on an intersection point of said photoelectric conversion signals and a predetermined slice level by the predetermined treatment, and a coma aberration of said projection optical system is calculated based on a calculation result.

Claim 17

The image forming properties measurement method according to claim 8, wherein said pattern consists of a line and space pattern having a periodicity in a direction corresponding to said second direction, and a phase difference between a first fundamental frequency component of said photoelectric conversion signals corresponding to a pitch of each said line pattern and a second fundamental frequency component of said photoelectric conversion signals corresponding to an entire width of said line and space pattern is calculated by the predetermined treatment and said coma aberration of the projection optical system is calculated based on a calculation result.

Claim 18

The image forming properties measurement method according to claim 8, wherein said pattern is a symmetric mark having at least two types of a line pattern with a different line width arranged in a predetermined interval in a direction corresponding to said second direction, and a deviation of symmetry of an aerial image of said pattern is calculated based on an intersection point of said photoelectric conversion signals and a predetermined slice level by the predetermined treatment, and a coma aberration of said projection optical system is obtained based on a calculation result.

Claim 19

An aerial image measurement unit that measures an aerial image of a predetermined pattern formed by a projection optical system, said measurement unit comprising: an illumination unit which illuminates said pattern to form an aerial image of said pattern onto an image plane via said projection optical system; a slit plate, which has at least one slit extending in a first direction within a two-dimensional plane perpendicular to an optical axis of said projection optical system of which the width in a second direction being perpendicular to said first direction is greater than zero, and equal to or below said wavelength λ of said illumination light divided by said numerical aperture N.A. of said projection optical system (λ/N.A.); a photoelectric conversion element which photo-electrically converts said illumination light having passed through said slit plate, and outputs a photoelectric conversion signal corresponding to a light intensity of said illumination light which has passed through said slit; and a processing unit which scans said slit plate in said second direction within said two-dimensional plane in the vicinity of said image plane in a state where said pattern is illuminated by said illumination unit and said aerial image is formed on said image plane, and measures a light intensity distribution corresponding to said aerial image based on said photoelectric conversion signal output from said photoelectric conversion element.

Claim 20

An exposure apparatus that transfers a circuit pattern formed on a mask onto a substrate via a projection optical system, said exposure apparatus comprising: a substrate stage which holds said substrate; and an aerial image measurement unit according to claim 19 which has an arrangement of said slit plate being integrally movable with said substrate stage.

Claim 21

The exposure apparatus according to claim 20, wherein said exposure apparatus further comprises a control unit which measures a light intensity distribution corresponding to aerial images of various mark patterns using said aerial

image measurement unit and obtains image forming properties of said projection optical system based on data of said light intensity distribution measured.

Claim 22

The exposure apparatus according to claim 20, said exposure apparatus further comprising: a mark detection system which detects a position of a mark on said substrate stage; and a control unit which detects a positional relationship between a projected position of said mask pattern by said projection optical system and said mark detection system using said aerial image measurement unit.

Detailed Description of the Invention

[0001]

Industrial Field of Utilization

The present invention relates to an aerial image measurement method, an image forming properties measurement method, an aerial image measurement unit, and an exposure apparatus,. More particularly, the present invention relates to an aerial image measurement method that measures an aerial image formed on an image plane by a projection optical system, an image forming properties measurement method that measures the image forming properties of the projection optical system utilizing the aerial image measurement method, an aerial image measurement unit to carry out the aerial image measurement method, and an exposure apparatus having the aerial image measurement unit.

[0002]

Prior Art

When devices such as a semiconductor device or a liquid crystal display device are conventionally manufactured in a photolithographic process, a projection exposure apparatus that transfers a pattern of a photomask or a reticle (hereinafter generally referred to as a "reticle") onto a substrate such as a wafer or glass plate on which a photosensitive agent such as a photoresist is coated on the surface via a projection optical system is used. The reduction projection exposure apparatus (generally referred to as a stepper) based on the step-and-repeat method, or the scanning projection exposure apparatus (generally referred to as a scanning stepper) based on the step-and-scan method are examples of such a projection exposure apparatus.

[0003]

In the case of manufacturing a semiconductor, or the like, it is necessary to overlay and form many layers of different circuit patterns on a substrate. Therefore, it is important to precisely overlay the reticle on which the circuit pattern is drawn with the pattern already formed on each shot area on the substrate. In order to perform such a precise overlay, it is a mandatory for the image forming characteristics of the projection optical system to be adjusted to a desired state.

[0004]

As a premise of adjusting the image forming characteristics of the projection optical system, the image forming characteristics have to be precisely measured. And as the measurement method of the image forming characteristics, the method is mainly used (hereinafter referred to as the "exposing method") where exposure is performed using a mask for measurement on which patterns for a predetermined measurement are formed, and the image forming characteristics are calculated based on measurement results of measuring a resist image, which is obtained by developing the substrate on which the projected image of the measurement pattern is transferred and formed. Other than this method, the method to calculate the image forming characteristics based on measurement results of measuring an aerial image (projection image) of the measurement pattern formed by the projection optical system by illuminating the mask for measurement with the illumination light (hereinafter referred to as the "aerial image measurement method") is also used, without substantial exposure.

[0005]

The conventional aerial image measurement was generally performed in the following manner. That is, for example, as is shown in FIG. 38A, an opening plate 123 on which a square opening 122 is formed, is arranged on a substrate stage. The opening plate 123 is scanned via the substrate stage in the direction indicated by the arrow A, with respect to the aerial image MP' of the measurement pattern on the reticle for measurement formed by the projection optical system (not shown in figures), and the illumination light which has passed through the opening 122 is photo-detected and photo-electrically converted by a photoelectric conversion element. With this photoelectric conversion, a photoelectric conversion signal (light intensity signal corresponding to the aerial image) as is shown in FIG. 38B, can be obtained. Next, by differentiating the waveform of the photoelectric conversion signal with reference to the main scanning direction shown in FIG. 38B, a differential waveform as is shown in FIG. 38C is obtained. And, based on the differential waveform, as is shown in FIG. 38C, a well-known predetermined signal processing such as the Fourier Transform Method is performed, and the optical image (aerial image) of the projected measurement marks is obtained.

[0006]

Details of such measurement of the aerial image and the detection of distortion and the like of the projection optical system based on this measurement are disclosed, for example, in Japanese Patent Laid Open (Unexamined) No. 10-209031.

[0007]

Problems to Be Solved by the Invention

With the conventional aerial image measurement method described above, however, since the aerial image intensity was measured by scanning a large opening as is shown in FIG. 38B, it turned out that a large scale of a low-frequency component was mixed in addition to the aerial frequency component that characterizes the profile of the aerial image. On the other hand, the dynamic range of the signal processing system arranged on the latter stage of the photoelectric conversion element is limited, and since the resolution of the signal processing system to the dynamic range is also limited (for example, around 16 bit at the current level), the S/N ratio of the signal component which reflects the profile of the aerial image turned out to be small. Therefore, the conventional aerial image measurement method was sensitive to noise, and the deterioration of the image profile was large when the aerial image was converted to the aerial image intensity signal, thus, it was difficult to measure the aerial image with a sufficient accuracy.

[0008]

Besides this method, conventionally, mainly for the purpose of detecting the image forming position of a pattern, details of a unit having a slit scanned with respect to the aerial image of the pattern are disclosed, for example, in Japanese Patent Laid Open No. 58-7823, and the like. With the unit disclosed in the publication, however, the width of the slit was set in correspondence with the shape of the mask pattern (reference pattern). Therefore, it was difficult to accurately measure the aerial image of patterns having various shapes (including sizes).

[0009]

The present invention has been made in consideration of the circumstances described above, and has as its first object the provision of an aerial image measurement method and an aerial image measurement unit that are capable of measuring an aerial image with a sufficient accuracy.

[0010]

The second object of the present invention is to provide an image forming properties measurement method that can accurately measure the image forming properties of the projection optical system.

[0011]

The third object of the present invention is to provide an exposure apparatus that contributes to improving the exposure accuracy.

[0012]

Means to Solve Problems

In general, the resolution (resolving power) R of a projection optical system in an exposure apparatus is expressed, well known as the Rayleigh criterion, as $R=k.\times\lambda./N.A.$ (λ is the wavelength of the illumination light, N.A. is the numerical aperture of the projection optical system, and k is a constant determined by the

photoresist process (the process coefficient) besides the resolution of the resist). The inventor focused on this point, and from the results of performing various experiments and the like, discovered that when the width of aperture used in aerial image measurement in the scanning direction was set considering at least either the illumination light wavelength λ or the numerical aperture N.A. of a projection optical system, a favorable result could be obtained in aerial image measurement. The aerial image measurement method related to the present invention is devised based on such new information by the inventor.

[0013]

According to the first aspect of this invention, there is provided an aerial image measurement method to measure an aerial image of a predetermined pattern formed by a projection optical system (PL), the measurement method including: the step of illuminating the pattern with illumination light (IL) and forming an aerial image of the pattern on an image plane via the projection optical system; and the step of scanning a slit plate (90), which has at least one slit extending in a first direction within a two-dimensional plane perpendicular to an optical axis of the projection optical system of which the width perpendicular to the first direction within the two-dimensional plane serving as a second direction is set in consideration of a wavelength λ of the illumination light, in the second direction within the two-dimensional plane close to the image plane, and photo-electrically converting the illumination light having passed through the slit and obtaining a photoelectric conversion signal which corresponds to an intensity of the illumination light having passed through the slit.

[0014]

With this method, the predetermined pattern is illuminated with the illumination light, and the aerial image of the pattern is formed on the image plane via the projection optical system. And, with respect to this aerial image, the slit plate is scanned in the second direction within the two-dimensional plane in the vicinity of the image plane. The slit plate, in this case, has at least one slit extending in the first direction within the two-dimensional plane perpendicular to the optical axis of the projection optical system of which the width perpendicular to the first direction within the two-dimensional plane serving as the second direction is set in consideration of the wavelength λ of the illumination light. Also, the illumination light having passed through the slit is photo-electrically converted and the photoconversion signal corresponding to the intensity of the illumination light that has passed through the slit is obtained. And, by performing a predetermined process on the photoconversion signal, the aerial image (image intensity distribution) can be obtained.

[0015]

That is, an aerial image of a predetermined pattern can be obtained based on the slit-scan method. In this case, since the width of the slit in the scanning direction is set with consideration of the wavelength of the illumination light, it becomes possible to measure the aerial image with sufficient accuracy.

[0016]

According to the first aspect of this invention, there is provided an aerial image measurement method to measure an aerial image of a predetermined pattern formed by a projection optical system, the measurement method including: the step of illuminating the pattern with illumination light and forming an aerial image of the pattern on an image plane via the projection optical system; and the step of scanning a slit plate, which has at least one slit extending in a first direction within a two-dimensional plane perpendicular to an optical axis of the projection optical system of which the width perpendicular to the first direction within the two-dimensional plane serving as a second direction is set in consideration of a numerical aperture N.A. of the projection optical system, in the second direction within the two-dimensional plane close to the image plane, and photo-electrically converting the illumination light having passed through the slit and obtaining a photoelectric conversion signal which corresponds to an intensity of the illumination light having passed through the slit.

[0017]

With this method, the predetermined pattern is illuminated with the illumination light, and the aerial image of the pattern is formed on the image plane via the projection optical system. And, with respect to this aerial image, the slit plate is scanned in the second direction within the two-dimensional plane in the vicinity of the image plane. The slit plate, in this case, has at least one slit extending in the first direction within the two-dimensional plane perpendicular to the optical axis of the projection optical system of which the width perpendicular to the first direction within the two-dimensional plane serving as the second direction is set in consideration of the numerical aperture N.A. of the projection optical system. Also, the illumination light having passed through the slit is photo-electrically converted and the photoconversion signal corresponding to the intensity of the illumination light that has passed through the slit is obtained. And, by performing a predetermined process on the photoconversion signal, the aerial image (image intensity distribution) can be obtained.

[0018]

That is, an aerial image of a predetermined pattern can be obtained based on the slit-scan method. In this case, since the width of the slit in the scanning direction is set with consideration of the numerical aperture N.A. of the projection optical system, it becomes possible to measure the aerial image with sufficient accuracy.

[0019]

With the aerial image measurement method according to the present invention recited in claims 1 and 2, as in the invention the first invention in claim 3, it is preferable for the width of the slit in the second direction to be greater than zero, and equal to or below the wavelength λ of the illumination light divided by the numerical aperture N.A. of the projection optical system (λ/N.A.). In this case, a width of the scanning direction of the slit is set by considering both of the two parameters that affect resolution, that is, wavelength λ and a numerical aperture N.A., and hence the aerial image can be measured with high precision, even compared with claim 1 and 2. The reason for setting the width of the slit in the scanning direction equal to or below (λ/N.A.), first of all, is because when the inventor repeatedly performed simulations and experiments under the conditions of the width of the slit in the scanning direction (referred to as 2D) as 2D=f(λ/N.A.)=n·(λ/N.A.), favorable results (sufficiently practical results) were obtained in the case when the coefficient was n=1. And, secondly, as will be referred to later on, since the photoelectric conversion signal above is to become a convolution of the slit and the intensity distribution of the aerial image, from the aspect of measurement accuracy, the width of the slit in the scanning direction 2D is better when narrower.

[0020]

In this case, as in the invention recited in claim 4, it is further preferable for the width of the slit in the second direction to be equal to or below the (λ/N.A.) multiplied by 0.8. As is mentioned above, from the aspect of measurement accuracy, the width of the slit in the slit is better when narrower, and according to the simulations and experiments performed by the inventor, it has been confirmed that the results are further practical when the width of the slit in the scanning direction 2D is equal to or below 80% of the (λ/N.A.).

[0021]

When considering the limitations from the aspect of throughput, however, if the width 2D is too narrow, the light intensity of the light having passed through the slit becomes too weak, and difficult to measure, therefore, a width of a certain range is necessary.

[0022]

With the aerial image measurement method according to the invention recited in claims 1 and 2, as in the invention recited in claim 5, the width of the slit in the second direction may be half a minimum pitch multiplied by an odd number, the minimum pitch being a pitch of a line and space pattern in a limit of resolution set by illumination conditions including properties of the illumination light and the type of the pattern.

[0023]

In the case of a normal pattern without using the phase-shifting method, under the conditions of conventional illumination, the minimum pitch referred to above is almost equal to λ/N.A. Whereas, in the case of a phase-shifting pattern, that is, in the case of a phase-shifting mask (phase-shifting reticle) pattern employing the phase-shifting method, it is confirmed that the minimum pitch becomes almost λ/(2N.A.). As the phase-shifting mask, the half-tone type, or the Levenson type, can be listed.

[0024]

With the aerial image measurement method according to the invention recited in claims 1 and 2, as in the invention recited in claim 6, when a wavelength of the illumination light is expressed as λ and a numerical aperture of the projection optical system is expressed as N.A., the width of the slit in the second direction may be set as {λ/(2N.A.)} multiplied by an odd number.

[0025]

With the aerial image measurement method according to the present invention recited in claims 1 to 6, as in the invention recited in claim 7, the measurement method can further include the steps of: obtaining a spatial frequency distribution by performing a Fourier Transform on the photoelectric conversion signal; converting the spatial frequency distribution into a spectrum distribution of its original aerial image by dividing the spatial frequency distribution with a frequency spectrum of the slit that is already known; and recovering the original aerial image by performing an inverse Fourier Transform on the spectrum distribution.

[0026]

According to this invention recited in claim 8, there is provided an image forming properties measurement method to measure image forming properties of a projection optical system, the measurement method including: the step of illuminating a predetermined pattern with illumination light and forming an aerial image of the pattern on an image plane via the projection optical system; the step of scanning a slit, which has at least one slit with a predetermined slit width extending in a first direction within a two-dimensional plane perpendicular to an optical axis of the projection optical system, within the two-dimensional plane close to the image plane in a second direction which is perpendicular to the first direction, and photo-electrically converting the illumination light having passed through the slit and obtaining a photoelectric conversion signal which corresponds to an intensity of the illumination light having passed through the slit; and the step of obtaining image forming properties of the projection optical system by repeatedly performing the predetermined treatment based on the photoelectric conversion signal.

[0027]

With this method, the predetermined pattern is illuminated with the illumination light, and the aerial image of the pattern is formed on the image plane via

the projection optical system. In this state, the slit plate is scanned within the two-dimensional plane close to the image plane in the second direction which is perpendicular to the first direction, and the illumination light having passed through the slit is photo-electrically converted and the photoelectric conversion signal which corresponds to the intensity of the illumination light having passed through the slit is obtained. In this case, the slit plate has at least one slit with a predetermined slit width extending in a first direction within a two-dimensional plane perpendicular to an optical axis of the projection optical system. And, based on the photodetection signal, the image forming properties of the projection optical system are obtained by repeatedly performing the predetermined treatment.

[0028]

That is, by the slit-scan method, the aerial image of the predetermined pattern can be obtained, and since the image forming properties of the projection optical system are obtained by repeatedly performing the predetermined treatment based on the obtained photodetection signal, it becomes possible to measure the image forming properties of the projection optical system with high precision.

[0029]

In this case, as in the invention recited in claim 9, the pattern can consist of a line and space pattern that has a periodicity in a direction corresponding to the second direction, detection of the photoelectric conversion signal can be repeated a plurality of times while changing a position of the slit plate in a direction of the optical axis, Fourier Transformation is performed respectively on a plurality of photoelectric conversion signals obtained by repeatedly performing said predetermined treatment in said detection; a contrast is obtained; which is an amplitude ratio of a first order frequency component and a zero order frequency component of respective signals and position of said optical axis is detected which corresponds to a photoelectric conversion signal which maximizes said contrast, to thereby detect a best focus position of a projection optical system. The contrast changes sensitively depending on the focus position (defocus amount); therefore, according to the present invention, the best focus position of the projection optical system can be accurately, and easily measured (set).

[0030]

In this case, as in the invention recited in claim 10, the method can further include the step of detecting an image plane shape of the projection optical system by repeatedly performing detection of the best focus position on a plurality of points distanced differently from an optical axis of the projection optical system. The image plane, or in other words, the best image forming plane, is a plane made up of a group of best focus points from innumerable points (that is, innumerable points that have different so-called image heights) of which the distance from the optical axis differs.

Therefore, by repeatedly performing detection of the best focus position on a plurality of points having a different distance from the optical axis of the projection optical system, and performing statistical processing based on the detection results, it becomes possible to obtain the image plane both easily and accurately.

[0031]

With the image forming properties measurement method according to the present invention recited in claim 9, as in the invention recited in claim 11, the measurement method can further include the step of: performing detection of the best focus position along an optical axis of the projection optical system repeatedly on a plurality of line and space patterns having a different pitch, and obtaining a spherical aberration of the projection optical system based on a difference of the best focus position corresponding to each of the patterns. The spherical aberration is a type of aperture aberration of the optical system, and is a phenomenon such that when light from object points on the optical axis having various apertures enters the optical system, the corresponding image point is not formed at one point. Accordingly, by repeatedly performing detection of the best focus position in the optical axis of the projection optical system on a plurality of line and space patterns having a different pitch, and based on the difference of the best focus position corresponding to each pattern obtained, the spherical aberration can be easily obtained by calculation.

[0032]

In this case, with the image forming properties measurement method according to the present invention recited in claim 8, as in the invention recited in claim 12, the pattern can include at least one rectangular pattern of which the width in the second direction is larger than a width of the slit in the second direction. Forming of said aerial image and detection of said photoelectric conversion signal are repeatedly performed on an aerial image of said pattern projected at different positions within an image field of said projection optical system, and a phase detection is performed based on a plurality of photoelectric conversion signals obtained by said predetermined repeated treatment, a position of an aerial image individually corresponding to said plurality of photoelectric conversion signals is respectively calculated based on a result of said phase detection, and at least one of a distortion and a magnification of said projection optical system is obtained based on said calculation results.

[0033]

Distortion, here, is an aberration of the projection optical system, and when distortion occurs a line originally straight turns out to be a curved image in the periphery within the image field and the aerial image of the pattern is formed deviated (laterally shifted) from the predetermined position on the image plane, as is with the case when magnification error occurs.

[0034]

According to the invention, the positional deviation of the aerial image of the pattern projected at different positions within the image field of the projection optical system can be respectively obtained with high precision by the phase detection method. As a consequence, at least either the distortion or magnification can be measured with high precision. The reason for the pattern to include at least one rectangular pattern of which the width in the second direction is larger than that of the slit, is because if the width of the pattern in the second direction is narrower than the slit, it becomes difficult to accurately measure the distortion due to the influence of other aberrations, such as coma aberration.

[0035]

With the image forming properties measurement method according to the present invention recited in claim 8, as recited in claim 13, in this case, the pattern can include at least one rectangular pattern of which the width in the second direction is larger than a width of the slit in the second direction, forming of said aerial image and detection of said photoelectric conversion signal are repeatedly performed on an aerial image of said pattern projected at different positions within an image field of said projection optical system, and a position of an aerial image individually corresponding to said plurality of photoelectric conversion signals is respectively calculated based on an intersection point of each of a plurality of photoelectric conversion signals obtained by said predetermined repeated treatment and a predetermined slice level, and at least one of a distortion and a magnification of said projection optical system is obtained based on said calculation results.

[0036]

According to the invention, the position of the aerial image of a pattern projected at different positions within the image field of the projection optical system can be respectively obtained with high precision by the edge detection method using the slice method. As a result, the distortion can be measured with high precision. Here, it is the same reason as in Claim 12 that said pattern includes at least one rectangular pattern of which the width in said second direction is larger than a width of said slit in said second direction.

[0037]

With the image forming properties measurement method according to the invention recited in claim 8, as in the invention recited in claim 14, the pattern can have a rectangular shape as a whole, and can consist of a line and space pattern having a periodicity in the first direction. In such a case, for example, when performing detection of the aerial image of the predetermined pattern by the slit-scan method the slit is relatively scanned in the direction perpendicular to the periodic direction of the pattern. As a consequence, when a rectangular pattern that has the same shape as the

entire shape of the pattern is slit-scanned, a signal of a similar aerial image can be obtained. This, for example, allows aerial image measurement equal to when a BOX mark pattern of 10 square μm (an inner BOX mark) is used, without actually forming such a mark pattern, since such a mark pattern is difficult to form due to dishing occurring in the recent CMP process.

[0038]

In the case, as in the invention in claim 15, forming of said aerial image and detection of said photoelectric conversion signal are repeatedly performed on an aerial image of said pattern projected at different positions within an image field of said projection optical system, and a position of an aerial image individually corresponding to said plurality of photoelectric conversion signals is respectively calculated based on an intersection point of each of a plurality of photoelectric conversion signals obtained by said predetermined repeated treatment and a predetermined slice level, and at least one of a distortion and a magnification of said projection optical system is obtained based on said calculation results.

[0039]

With the image forming properties measurement method according to the invention recited in claim 8, as in the invention recited in claim 16, in the case that said pattern consists of a line and space pattern having a periodicity in a direction corresponding to said second direction, and, an abnormal line width value of each line pattern is calculated based on an intersection point of said photoelectric conversion signals and a predetermined slice level by performing the predetermined treatment, a coma aberration of said projection optical system is calculated based on a calculation result.

[0040]

The coma aberration is an aberration of the lens due to different magnifications in various zones of the lens, and occurs at the image portions far from the main axis of the projection optical system. Accordingly, at the position far from the optical axis, the line width of each line pattern becomes different depending on the coma aberration in the aerial image of the line and space pattern. According to the invention where the abnormal line width value of each line pattern is detected based on the edge detection method using the slice method, thus, it becomes possible to measure the coma aberration in a simple manner, with high accuracy.

[0041]

With the image forming properties measurement method according to the invention recited in claim 8, as in the invention recited in claim 17, in the case that said pattern consists of a line and space pattern having a periodicity in a direction corresponding to said second direction, a phase difference is calculated between a first fundamental frequency component of said photoelectric conversion signals

corresponding to a pitch of said line pattern and a second fundamental frequency component of said photoelectric conversion signals corresponding to an entire width of said line and space pattern by the predetermined treatment, and said coma aberration of the projection optical system is obtained based on a calculation result. The narrower the width of the line pattern of the aerial image is in the scanning direction, the more the influence of the coma increases. As a consequence, the effect on coma aberration on the aerial image of each of the line pattern of line and space is different from the effect on coma aberration on the aerial image of the pattern when setting the entire width of the line and space pattern as one pattern. Accordingly, a phase difference is calculated between a first fundamental frequency component of the photoelectric conversion signals corresponding to a pitch of line pattern and a second fundamental frequency component of the photoelectric conversion signals corresponding to an entire width of the line and space pattern. According of the invention where the coma aberration of the projection optical system can be calculated based on a calculation result, the coma aberration of the optical projection system can be obtained with high precision by the phase detection method.

[0042]

With the image forming properties measurement method according to the invention recited in claim 8, as in the invention recited in claim 18, in the case that said pattern is a symmetric mark pattern having at least two types of a line pattern with a different line width arranged in a predetermined interval in a direction corresponding to said second direction, a deviation of symmetry of an aerial image of said pattern is calculated, and a coma aberration of said projection optical system is obtained based on a calculation result, based on an intersection point of said photoelectric conversion signals and a predetermined slice level by the predetermined treatment.

The narrower the width of the line pattern of the aerial image is in the scanning direction, the more the aerial image of line pattern deviates by the influence of the coma. As a consequence, the symmetry of the aerial image of the symmetric mark pattern having a plurality of line pattern types with a different line width arranged in a predetermined interval in a direction corresponding to the scanning direction deviates greatly, the larger the coma is. Accordingly, by the edge detection method using the slice method, the deviation in symmetry of the symmetric mark pattern of the aerial image can be calculated, and based on the calculation results the coma of the projection optical system can be obtained, thus the coma of the projection optical system can be obtained with good accuracy.

[0043]

In the invention as recited in claim 19, an aerial image measurement unit measures an aerial image of a predetermined pattern formed by a projection optical

system, said measurement unit comprising: an illumination unit (10) which illuminates said pattern to form an aerial image of said pattern onto an image plane via said projection optical system;
at least a slit plate (90), which has at least one slit extending in a first direction within a two-dimensional plane perpendicular to an optical axis of said projection optical system of which the width in a second direction being perpendicular to said first direction is greater than zero, and equal to or below said wavelength λ of said illumination light divided by said numerical aperture N.A. of said projection optical system (λ/N.A.);
a photoelectric conversion element (24) which photo-electrically converts said illumination light having passed through said slit plate, and outputs a photoelectric conversion signal corresponding to a light intensity of said illumination light which has passed through said slit;
and a processing unit (20) which scans said slit plate in said second direction within said two-dimensional plane in the vicinity of said image plane in a state where said pattern is illuminated by said illumination unit and said aerial image is formed on said image plane, and measures a light intensity distribution corresponding to said aerial image based on said photoelectric conversion signal output from said photoelectric conversion element.

[0044]

With this unit, the illumination unit illuminates the predetermined pattern, and the aerial image of the pattern is formed on the image plane via the projection optical system. The processing unit then scans the slit plate that has at least one slit extending in the first direction within the two-dimensional plane perpendicular to the optical axis of the projection optical system in the second direction within the two-dimensional plane in the vicinity of the image plane with respect to the aerial image formed. And, the processing unit also measures the light intensity distribution corresponding to the aerial image based on the photoelectric conversion signal (electric signals of the illumination light having passed through the slit during scanning and photo-electrically converted) output from the photoelectric conversion element. That is, the aerial image of the predetermined pattern is measured in this manner, by the slit-scan method. In addition, in this case, since the width of the slit in the scanning direction formed on the slit plate is equal to or below (λ/N.A.), the measurement of the aerial image can be performed with sufficiently practical high precision, as Claim 3.

[0045]

According to the invention as recited in claim 20, there is provided an exposure apparatus that transfers a circuit pattern formed on a mask (R) onto a substrate (W) via a projection optical system (PL), the exposure apparatus

comprising: a substrate stage (WST) which holds the substrate; and an aerial image measurement unit as recited in claim 19 which has an arrangement of the slit plate (90) being integrally movable with the substrate stage.

[0046]

With this apparatus, since it includes the aerial image measurement unit as recited in claim 18 that has an arrangement of the slit plate being integrally movable with the substrate stage, it becomes possible, for example, to form various measurement pattern on the mask and to measure the aerial image of the various measurement pattern with high precision by the aerial image measurement unit while moving the slit plate integrally with the substrate stage. Accordingly, it becomes possible to improve the exposure accuracy in the long run, by using the measurement results and performing, for example, initial adjustment of the image forming properties of the projection optical system and the like. As a consequence, this can lead to improving the yield of the exposing device high precision.

[0047]

In this case, as recited in claim 21, the exposure apparatus can further include a control unit (20) which measures a light intensity distribution corresponding to aerial images of various mark patterns using the aerial image measurement unit and obtains image forming properties of the projection optical system based on data of the light intensity distribution measured. In such a case, the control unit measures the light intensity distribution corresponding to the aerial images of various mark patterns, and based on the data of the light intensity distribution measured, the image forming properties of the projection optical system are obtained. Thus, it becomes possible to obtain the image forming properties of the projection optical system when necessary, and this allows adjustment of the image forming properties of the projection optical system prior to the beginning of exposure based on the obtained image forming properties. Accordingly, improving the exposure accuracy becomes possible.

[0048]

With the exposure apparatus according to the present invention recited in claim 20, as in the invention recited in claim 22, the exposure apparatus can further include: a mark detection system which detects a position of a mark on the substrate stage (ALG1 or ALG2); and a control unit which detects a positional relationship between a projected position of the mask pattern by the projection optical system and the mark detection system using the aerial image measurement unit. In such a case, the control unit detects the positional relationship between the projected position of the mask pattern by the projection optical system, or in other words, the image forming position of the aerial image of the pattern and the mark detection system (that is, the so-called baseline amount of the mark detection system) using the aerial image

measurement unit. Due to the controlling unit, on measuring the baseline amount, since the projection position of the mask pattern can be measured directly by the aerial image measurement unit, a baseline amount measurement with high accuracy is possible compared with the case when the projection position of the mask pattern is measured indirectly using the fiducial mark plate and the reticle microscope. Accordingly, by controlling the position of the substrate during exposure and the like using this baseline amount, the exposure accuracy can be improved due to improvement in the overlay accuracy of the mask and the substrate.

[0049]

Embodiments

The First Embodiment

The first embodiment of the present invention will be described below with reference to FIGS. 1 to 34.

[0050]

FIG. 1 shows a schematic arrangement of an exposure apparatus 100 related to the first embodiment. The exposure apparatus 100 is a scanning projection exposure apparatus, that is, the so-called scanning stepper, based on the step-and-scan method.

[0051]

The exposure apparatus 100 includes: an illumination system 10, which includes a light source and an illumination optical system; a reticle stage RST, which holds the reticle R serving as a mask; a projection optical system PL; a wafer stage WST as a substrate stage, which holds the wafer W serving as a substrate and is capable of moving freely within an XY plane; and a control system and the like to control these parts.

[0052]

The illumination system 10 has a structure including: a light source; an illuminance uniformity optical system (made up of a collimator lens, a fly-eye lens, and the like); a relay lens system; a reticle blind serving as an illumination aperture stop; a condenser lens system; and the like (all are omitted in FIG. 1).

[0053]

As the light source, in this embodiment, an excimer laser light source that emits the KrF excimer laser beam (wavelength: 248 nm) or the ArF excimer laser beam (wavelength: 193 nm) is to be used as an example.

[0054]

The reticle blind is made up of a fixed reticle blind of which the opening shape is fixed (not shown in figures) and a movable reticle blind 12 of which the opening shape is variable (omitted in FIG. 1, refer to FIG. 2). The fixed reticle blind is arranged in the vicinity of the pattern surface of the reticle R or on a surface slightly defocused from the conjugate plane relative to the pattern surface of the reticle R, and

a rectangular opening which sets the rectangular slit-shaped illumination area IAR is formed on the reticle R. In addition, the movable reticle blind 12 is arranged on the conjugate plane relative to the pattern surface of the reticle R close to the fixed reticle blind, and has an opening that is variable in position, of which the directions correspond to the scanning direction (in this case, the Y-axis direction being perpendicular to the surface of FIG. 1) and the non-scanning direction (in this case, the X-axis direction being the horizontal direction in the surface of FIG. 1) during scanning exposure, and in width.

[0055]

With the illumination system 10, the illumination light, which is generated at the light source and serves as the exposure light (hereinafter referred to as the "illumination light IL"), passes through a shutter (not shown in figures) and then is converted to a beam having an almost unified illumination distribution by the illuminance uniformity optical system. The illumination light IL emitted from the illuminance uniformity optical system reaches the reticle blind through the relay lens system. After passing through the reticle blind, the illumination light IL passes through the relay lens system, the condenser lens system, and then illuminates the illumination area IAR (illumination region of square-shaped slit being elongated to X-axis direction and having a predetermined width to Y-axis direction) of the reticle R, on which the circuit pattern, or the like is drawn, with a uniform illuminance.

[0056]

The main controller 20 controls the movable reticle blind 12 at the beginning and end of scanning exposure, and by further restricting the illumination area IAR, exposure on unnecessary portions is to be avoided. In addition, in this embodiment, the movable reticle blind 12 is also used to set the illumination area when the aerial image is measured with the aerial image measurement unit, which will be described later on in the description.

[0057]

On the reticle stage RST, the reticle R is fixed by, for example, vacuum chucking (or electrostatic adsorption). The reticle stage RST, in this case, can be finely driven two-dimensionally (in the X-axis direction, the Y-axis direction perpendicular to X-axis, and the rotational direction (θz direction) around the Z-axis perpendicular to XY plane) within an XY plane that is perpendicular to the optical axis AX of the projection optical system PL (to be described later) by a reticle stage driving system not shown, which includes a linear motor and the like. The reticle stage RST is also movable in the Y-axis direction at a designated scanning velocity on a reticle base not shown. The reticle stage RST has a movement stroke of Y direction such that the entire reticle R crosses the optical axis of at least the projection optical system PL.

[0058]

On the reticle stage RST, a movable mirror 15 is fixed to reflect the laser beam emitted from the reticle laser interferometer (hereinafter referred to as "reticle interferometer") 13. The position of the reticle stage RST within the XY plane is detected at all times by the reticle interferometer 13 at, for example, a resolution of around 0.5 to 1 nm. In actual, on the reticle stage RST, a movable mirror having a reflection surface perpendicular to the scanning direction (the Y-axis direction) during scanning exposure and a movable mirror having a reflection surface perpendicular to the non-scanning direction (the X-axis direction) are arranged, as well as the reticle interferometer 13 being arranged on at least one axis in the Y-axis direction and at least two axes in the X-axis direction. In FIG. 1, however, these are representatively indicated as the movable mirror 15 and the reticle interferometer 13.

[0059]

The positional information of the reticle stage RST is sent from the reticle interferometer 13 to the main controller 20, which consists of a workstation (or a microcomputer). The main controller 20 then controls and drives the reticle stage RST via the reticle stage driving system, based on the positional information of the reticle stage RST.

[0060]

The projection optical system PL is arranged below the reticle stage RST as is shown in FIG. 1, and the direction of the optical axis AX is the Z-axis direction. The projection optical system is a double telecentric reduction system, and employs a refraction optical system made up of a plurality of lens elements arranged along the direction of the optical axis AX in predetermined intervals. The projection magnification of the projection optical system PL is, for example, 1/5. Therefore, when the illumination light IL from the illumination system 10 illuminates the slit-shaped illumination area IAR on the reticle R, the illumination light IL which passes through the reticle R forms a reduced image (a partial inverted image) of the circuit pattern of the reticle R corresponding to the inner area of the illumination area IAR via the projection optical system PL, on an exposure area IA of the wafer W, which is conjugate to the illumination area IAR and has a photoresist coated on its surface.

[0061]

The wafer stage WST is driven freely along the upper surface of a stage base 16 within the XY two-dimensional plane (including the θz rotation) by a wafer stage driving system (not shown in figures) made up of, for example, a two-dimensional magnetically levitated linear actuator. The two-dimensional magnetically levitated linear actuator has a Z driving coil, in addition to the X driving coil and Y driving coil. Therefore, the wafer stage WST can be finely driven in directions of three degrees of freedom, in the Z, θx, and θy.

[0062]

On the wafer stage WST, a wafer holder 25 is arranged, and the wafer holder 25 holds the wafer W by, for example, vacuum chucking (or electrostatic adsorption).

[0063]

In the case of using a two-dimensional moving stage which can be driven only within the XY two-dimensional plane by a driving system such as a linear motor or a planar motor, instead of the wafer stage WST, the wafer holder 25 may be mounted on the two-dimensional moving stage via a Z leveling table. The Z leveling table is capable of being finely driven in directions of three degrees of freedom, in the Z, θx, and θy directions, by for example, a voice coil motor and the like.

[0064]

On the wafer stage WST, a movable mirror 27, which reflects the laser beam from the wafer laser interferometer (hereinafter referred to as a "wafer interferometer") 31, is arranged. The wafer interferometer 31, which is arranged external to the wafer stage WST, detects the position of the wafer stage WST at all times in XY plane, at a resolution of, for example, around 0.5 to 1 nm.

[0065]

In actual, on the wafer stage WST, a movable mirror having a reflection surface perpendicular to the scanning direction which is the Y-axis direction on scanning exposure and a movable mirror having a reflection surface perpendicular to the non-scanning direction which is the X-axis direction are arranged, in addition to the wafer interferometer 31 being arranged respectively in one-axis in the Y-axis direction and two axes in the X-axis direction. In FIG. 1, however, these are representatively indicated as the movable mirror 27 and the wafer interferometer 31. The positional information (or the velocity information) of the wafer stage WST is sent to the main controller 20, and the main controller 20 controls the position of the wafer stage WST within the XY plane via the wafer stage driving system (not shown in figures), based on the positional information (or the velocity information).

[0066]

In addition, an aerial image measurement unit 59 is partially arranged on the wafer stage WST. The aerial image measurement unit 59 is used to measure the image forming properties of the projection optical system PL, and the structure will now be described in detail. As is shown in FIG. 2, the aerial image measurement unit 59 is provided in a projected portion 58a, which is arranged projecting on the upper surface of the wafer stage WST on one end of the stage and has an opening formed on the upper side. The aerial image measurement unit 59 is fitted into the opening from above so as to seal opening of the projected portion 58a, and is made up of a photodetection glass 82 being rectangular in a planar view and a reflection film 83 also serving as a light shielding film, which is formed on the upper surface of the

photodetection glass 82. And a slit 22 is formed on a part of the reflection film 83. Within the wafer stage WST underneath the slit 22, a relay optical system (84, 86) made up of the lenses 84 and 86, is arranged with the mirror 88 (herein, photo-detected optical system is constituted by lenses 84, 86 and mirror 88) in between to horizontally deflect the optical path of the illumination light (image light) that has been relayed for a predetermined optical path is fixed, and an optical sensor 24, or the like is contained as a photoelectric conversion device.

[0067]

As the material for the photodetection glass 82, in this embodiment, materials such as synthetic quartz or fluorite that have high transmittance to the KrF excimer laser beam or the ArF excimer laser beam, is to be used. As the optical sensor 24, a photoconversion element (photodetection element) capable of accurately detecting faint light, such as a photo multiplier tube is used. Further, in the embodiment a slit plate is formed by a photodetection glass 82 and a reflection film 83. In the following description, a slit plate formed by a photodetection glass 82 and a reflection film 83 is suitably referred to as "slit plate 90". Further, as described above, the slit 22 is formed in the reflection film 83, but it will be considered and described that the slit 22 is formed in the slit plate 90 for convenience in the following.

[0068]

In the embodiment, with the aerial image measurement unit 59 that has the arrangement described above, on measuring the projected image (aerial image) of the measurement marks formed on the reticle R via the projection optical system PL (this will be described later), when the illumination light IL having passed through the projection optical system PL illuminates the slit plate 90 constituting the aerial image measurement unit 59, the illumination light IL that has passed through the slit 22 on the slit plate 90 is photo-detected in the optical sensor 24 through the photodetection optical system (84, 86, 88) and the photoelectric conversion signals P (light amount signals) from the optical sensor 24 according to the photo-detected amount are output to the main controller 20.

[0069]

Further, the optical sensor 24 need not be provided in the wafer stage WST, for example, in the same manner as the aerial image measurement unit 59' shown in FIG. 3, the optical sensor 24 may be disposed in the outside of the wafer stage WST. That is, as is shown in FIG. 3, on the wafer stage WST, two projected portions 58a and 58b are arranged, with the upper surface of the projected portions 58a and 58b arranged at almost the same surface as the wafer W surface. Likewise with the case in FIG. 2, a slit plate 90 having an identical arrangement is arranged in the projected portion 58a, and underneath the slit plate 90 inside the wafer stage WST, lenses 84 and 86, and a mirror 88 are arranged in an identical positional relationship as in FIG.

2. In this case, however, within the wafer stage WST, a light guide 85 is also housed. The light entering end 85a of the light guide 85 is arranged at a position conjugate to the photo-detecting plane where the slit 22 is formed. In addition, the outgoing end 85b of the light guide 85 is arranged almost directly under the light transmittance lens 87, which is fixed to the upper surface of the projected portion 58b.

[0070]

Above the light transmittance lens 87, a photodetection lens 89 of which the diameter is larger than that of the light transmittance lens 87 is arranged. And further above the photodetection lens 89 at a position conjugate to the outgoing end 85b, an optical sensor 24 is arranged. The photodetection lens 89 and the optical sensor 24 are housed in a case 92 with the positional relationship described above maintained, and the case 92 is fixed to a fixed member (not shown in figures).

[0071]

With the aerial image measurement unit 59' indicated in FIG. 3, as described below, on measuring the projected image (aerial image) of the measurement pattern formed on the reticle R via the projection optical system PL, when the illumination light IL having passed through the projection optical system PL illuminates the slit plate 90 that structure the aerial image measurement unit 59’, the illumination light IL that has passed through the slit 22 on the slit plate 90 is incident on the light entering end 85a of the light guide 85 after passing through the lens 84, the mirror 88, and the lens 86. The light guided by the light guide 85 is guided out of the wafer stage WST via the light transmittance lens 87, after being emitted from the outgoing end 85b of the light guide 85. And the light guided outside the wafer stage WST is photo-detected by the optical sensor 24 via the photodetection lens 89, and the photoelectric conversion signals (light amount signals) P from the optical sensor 24 corresponding to the photo-detected amount is sent to the main controller 20.

[0072]

In this case, measurement of the projected image of the measurement pattern is to be performed based on the slit-scan method, therefore, during this operation the photodetection lens 89 and the optical sensor 24 is to move with respect to the light transmittance lens 87. So, with the aerial image measurement unit 59', the size of each lens is set so that all light having passed through the light transmittance lens 87, which moves within a predetermined range, is incident on the photodetection lens 89.

[0073]

With the aerial image measurement unit 59', a light guiding portion is structured to guide the light that has passed through the slit 22 out of the wafer stage WST by the slit plate 90, the lenses 84 and 86, and the mirror 88, the light guide 85, and the light transmittance lens 87. A photodetection portion is structured to photodetect light which is guided outside the wafer stage WST by the photodetection

lens 89 and the optical sensor 24. In this case, as well, the light guiding portion and the photodetection portion referred to earlier are mechanically separate. And the light guiding portion and the photodetection portion are optically connected via the light transmittance lens 87 and the photodetection lens 89 only when the aerial image measurement is performed.

[0074]

That is, with the aerial image measurement unit 59', since the optical sensor 24 is arranged at a predetermined position external to the wafer stage WST, the heat generated by the optical sensor 24 does not have an adverse effect on the measurement precision and the like of the laser interferometer 31. In addition, since the external portion and the internal portion of the wafer stage WST is not connected with a light guide and the like, the driving accuracy of the wafer stage WST is not adversely affected as in the case when the external portion and the internal portion of the wafer stage WST is connected with a light guide and the like.

[0075]

Details on the shape, size and the like of the slit 22 formed on the slit plate 90 structuring the aerial image measurement unit 59 (or 59'), the aerial image measurement method using the aerial image measurement unit 59 (or 59'), and the measurement method of the image forming characteristics will be described later in the description.

[0076]

Referring back to FIG. 1, on the side surface of the projection optical system PL, an off-axis alignment microscope ALG1 serving as a mark detection system to detect the alignment marks on the wafer W (position alignment mark) is arranged. In this embodiment, as the alignment microscope ALG1, an alignment sensor based on the image processing method, or the so-called FIA (Field Image Alignment) system is used. As is shown in FIG. 2, the structure of the alignment microscope ALG1 includes an alignment light source 32, a half mirror 34, a first objective lens 36, a second objective lens 38, a pickup device (CCD) 40, and the like. As the alignment light source 32, a light source that emits a broadband illumination light such as a halogen lamp is used. With the alignment microscope ALG1, as is shown in FIG. 4, the illumination light emitted from the light source 32 illuminates the alignment mark Mw on the wafer W via the half mirror 34 and the first objective lens 36, and the light reflected off the alignment mark portion is photo-detected by the pickup device 40 via the first objective lens 36, half mirror 34, and the second objective lens 38. In this manner, the bright-field image of the alignment mark Mw is formed on the photodetection surface of the pickup device. And the photoelectric conversion signals corresponding to the bright-field image, in other words, the light intensity signals corresponding to the reflection image of the alignment mark Mw are sent to the main

controller 20 from a pick up device 40. The main controller 20 then calculates the position of the alignment mark Mw with the detection center of the alignment microscope ALG as the reference based on the light intensity signals. It also calculates the coordinate position of the alignment mark Mw in the stage coordinate system set by the optical axis of the wafer interferometer 31, based on the calculation results on the position of the alignment mark Mw and the positional information on the wafer stage WST which is output from the wafer interferometer 31.

[0077]

Furthermore, as is shown in FIG. 1, the exposure apparatus 100 in this embodiment has a light source of which on/off is controlled by the main controller 20, and a multiple focus position detection system (a focus sensor) based on the oblique incident method is arranged, consisting of an irradiation optical system 60a which irradiates light from an incident direction with respect to the optical axis AX to form multiple pinhole or slit images toward the image forming plane of the projection optical system PL, and of a photodetection optical system 60b which photo-detects the light reflected off the surface of the wafer W. By controlling the tilt of the plane-parallel plate arranged within the photodetection optical system 60b (not shown in figures) with respect to the optical axis of the reflected light, the main controller 20 provides an offset corresponding to the focus change of the projection optical system PL to the focus detection system (60a, 60b) and performs calibration. Details on the structure of the multiple focus position detection system (a focus sensor) similar to the focus detection system (60a, 60b) used in the embodiment, are disclosed in, for example, Japanese Patent Laid Open No. 06-283403.

[0078]

In the main controller 20, the multiple focus position detection system controls the movement of the wafer stage WST in the Z-position and the pitch amount and rolling amount (that is, rotation in the θx and θy directions) via the wafer stage driving system (not shown in figures), so that the defocus becomes zero based on defocus signals from the photodetection optical system 60b such as the S-curve signals upon scanning exposure (to be described later), and thereby to perform automatic focusing, in addition to automatic leveling.

[0079]

Following is a brief description of the operations in the exposure process of the exposure apparatus 100 in this embodiment.

[0080]

First of all, the reticle R is carried by a reticle carriage system (not shown in figures) and is held by adsorption on the reticle stage RST at the loading position. The main controller 20 then controls the position of the wafer stage WST and the reticle stage RST, measures (refer to FIG. 2)the projected image (aerial image) of the

reticle alignment marks (not shown in figures) formed on the reticle R using the aerial image measurement unit 59 in the manner which will be described later on, and obtains the projection position of the reticle pattern image. That is, the reticle alignment is performed.

[0081]

Next, the main controller 20 moves the wafer stage WST so that the aerial image measurement unit 59 is positioned directly below the alignment microscope ALG1, where the alignment optical system ALG1 detects the position of the slit 22, which is the positional reference of the aerial image measurement unit 59. In FIG. 5 it is represented that the slit 22 is detected by the alignment optical system ALG1. The main controller 20 obtains the positional relationship between the projection position of the pattern image of the reticle R and the alignment optical system ALG1 based on the detection signals of the alignment microscope ALG1, the measurement values of the wafer interferometer 31 in this state, and the projection position of the reticle pattern image previously obtained. In other words, the baseline amount of the alignment microscope ALG1 is obtained.

[0082]

When such baseline measurement is completed, the main controller 20 performs wafer alignment such as EGA (Enhanced Global Alignment), which details are disclosed in, for example, Japanese Patent Laid Open No. 61-44429 and the position of all the shot areas on the wafer W is obtained. Upon this wafer alignment, of the plurality of shot as on the wafer W, the wafer alignment mark Mw of a predetermined sample shot area decided in advance is measured in the manner described earlier (refer to FIG. 2) with the alignment microscope ALG1.

[0083]

The main controller 20 then sets the reticle stage RST to the scanning starting position and also sets the wafer stage WST to the scanning starting position to expose the first shot area, based on the positional information on each shot area on the wafer W and the baseline amount obtained above while monitoring the positional information sent from the interferometers 31 and 13.

[0084]

That is, the main controller 20 starts the relative scanning in opposite directions between the reticle stage RST and the wafer stage WST along the Y-axis, and when both stages RST and WST respectively reach their target scanning velocities, the exposing light EL starts to illuminate the pattern area of the reticle R, thus scanning exposure begins. Prior to this scanning exposure, the light source starts emitting light, however, since the main controller 20 controls the movement of each blade of the movable reticle blind constituting the reticle blind in synchronous with the movement of the reticle stage RST, irradiation of the exposure light EL on areas

other than the pattern area on the reticle R can be prevented likewise with the scanning steppers in general.

[0085]

The main controller 20 synchronously controls the reticle stage RST and the wafer stage WST so that especially during the scanning exposure described above, the movement velocity Vr in the Y-axis direction of the reticle stage RST and the movement velocity Vw in the X-axis direction of the wafer stage WST are maintained at a velocity ratio which corresponds to the projection magnification of the projection optical system PL.

[0086]

Then, different areas in the pattern area of the reticle R are sequentially illuminated with the ultraviolet pulse light, and by completing illumination of the entire pattern area, scanning exposure on the first shot area on the wafer W is consequently completed. In this manner, the circuit pattern of the reticle R is reduced and transferred onto the first shot area via the projection optical system PL.

[0087]

When scanning exposure on the first shot area is completed in this manner, stepping operation is performed between shot areas to move the wafer stage WST to the scanning starting position for exposure on the second shot area. And scanning exposure is similarly performed as above on the second shot area. From then onward, on and after the third shot area, the same operation is performed.

[0088]

Thus, the stepping operation in between shot areas and the scanning exposure operation on the shot area are repeatedly performed, and the pattern of the reticle R is transferred onto all the shot areas on the wafer W by the step-and-scan method.

[0089]

During the scanning exposure described above, interval between the wafer W surface and the projection optical system PL (the image plane thereof), and tilt with reference to XY plane (the image plane) are measured using the focus sensor (60a, 60b) integrally fixed to the projection optical system PL. and the wafer stage WST is controlled such that interval between wafer W surface and projection optical system PL by the main controller 20, and parallelity are constant all the time.

[0090]

In order to accurately overlay the pattern of the reticle R onto the pattern already formed on the shot area on the wafer W during the scanning exposure described above, it is important for the image forming properties (including the image forming characteristics) of the projection optical system PL and the baseline amount to be accurately measured, and the image forming properties of the projection optical system PL to be adjusted to a desired state.

[0091]

In this embodiment, the aerial image measurement unit 59 or 59' (hereinafter, typically refer to "aerial image measurement unit 59") referred to earlier is used to measure the image forming properties. The aerial image measurement by the aerial image measurement unit 59 and the measurement, or the like of the image forming properties of the projection optical system PL will now be described in detail.

[0092]

FIG. 2 shows a state where the aerial image of the measurement pattern formed on the reticle R is being measured using the aerial image measurement unit 59. As reticles R, it is possible to use a reticle made solely for aerial image measurement, or a reticle used for manufacturing a device that has the measurement mark only for measurement formed on the reticle. Instead of these reticles, fixed mark plate (refer to reticle fiducial mark plate) which is composed of glass material having the same as reticle in reticle stage RST is provided, and the measurement mark (measurement pattern) may be formed in the mark plate.

[0093]

As in shown FIG 2, the measurement pattern PM which is composed of line and space mark with the pediodicity in the X-axis direction at the predetermined portion is formed in the reticle R. Further, as shown in FIG. 6A, the slit 22 which extends to the Y-axis direction and has the prescribed width 2D is formed in the slit plate 90 of the aerial image measurement unit 59. Further, hereinafter, line and space is referred to as "L/S" suitably.

[0094]

When the aerial image is measured, the main controller 20 drives the movable reticle blind 12 via the blind driving unit (not shown in figures), and the illumination area of the illumination light IL of the reticle R is restricted only to the measurement pattern PM, as is shown in FIG. 2. In this state, when the illumination light IL is irradiated on the reticle R, the light (the illumination light IL) diffracted and scattered by the measurement pattern PM is refracted by the projection optical system PL as is shown in FIG. 2, and the aerial image (projected image) PM' of the measurement mark PM is formed on the image plane of the projection optical system PL. At this point, the wafer stage WST is to be positioned so that the aerial image PM' is formed on the +X side (or the -X side) of the slit 22 on the slit plate 90 of the aerial image measurement unit 59. FIG. 6A is a planar view of the aerial image measurement unit 59 in such a state.

[0095]

And, when the main controller 20 drives the wafer stage WST in the +X direction via the wafer stage driving system, as is indicated with the arrow F in FIG. 6A, the slit 22 is scanned in the X-axis direction with respect to the aerial image PM'.

During this scanning, the light (illumination light IL) which passes through the slit 22 is photo-detected by the optical sensor 24 via the photodetection optical system within the wafer stage WST (in the case of FIG. 3, light guiding portion and photodetection lens), and the photoelectric conversion signals are sent to the main controller 20. The main controller 20 then measures the light intensity distribution corresponding to the aerial image PM' through signal processing system not shown, based on the photoelectric conversion signals.

[0096]

FIG. 6B shows and example of a photoelectric conversion signal (light intensity signal) P that can be obtained on the aerial image measurement described above.

[0097]

In this case, the image of the aerial image PM' averages, due to the influence of the width (2D) of the slit 22 in the scanning direction (not the scanning direction in scanning and exposure, but the scanning direction with reference to the aerial image, that is X-axis direction).

[0098]

Accordingly, when the slit is expressed as p(x), the intensity distribution of the aerial image as i(x), and the observed light intensity signal as m(x), the relation of the intensity distribution i(x) of the aerial image with the observed light intensity signal m(x) can be expressed as the following equation (1). In equation (1), the unit of the intensity distribution i(x) and the observed light intensity signal m(x) is the intensity per unit length.

[0099]

[Formula 1]

$$m(x) = \int_{-\infty}^{\infty} p(x-u) \cdot i(u)\, du \quad \cdots (1)$$

[0100]

[Formula 2]

$$p(x) = \begin{cases} 1 (|x| \leq D) \\ 0 (|x| > D) \end{cases} \quad \cdots (2)$$

[0101]

That is, the observed light intensity signal m(x) is a convolution of the slit p (x) and the intensity distribution of the aerial image i(x).

[0102]

Accordingly, it is better for the width of the slit 2D in the scanning direction (hereinafter simply referred to as "slit width") to be narrower, from the aspect of measurement precision.

[0103]

The inventor repeatedly performed various simulations and experiments, or the like expressing the slit width 2D using the wavelength λ of the illumination light IL and the function f (λ/N.A.) of the numerical aperture N.A. of the projection optical system PL. As a result, it was confirmed that in the case the slit width 2D is 2D=n·(λ/N.A.) and the coefficient also n=<l, the experiment proved to be sufficiently practical, and especially when the coefficient is n=<0.8, proved to be more practical. "Practical", in this case, means that deterioration of the image profile is small when converting the aerial image into the aerial image intensity signal, therefore, the signal processing system arranged after the optical sensor 24 (photoelectric conversion element) does not require a dynamic range and a sufficient precision can be acquired.

[0104]

An example of the favorable result described above, is shown, for example, in the following Table 1.

[0105]

[TABLE 1]

Wavelength (nm)	Numerical Aperture of projection lens	(A) Wavelength/Numerical Aperture (nm) of projection lens	B=A×0.8
248	0.68	364	291
248	0.75	331	264
193	0.65	297	238
193	0.75	257	206
193	0.85	227	182

[0106]

As can be seen from Table 1, the substantial slit width (aperture size: B in Table 1) differs depending on the numerical aperture and the wavelength, however, the appropriate value is generally 300 nm or under. Slits of this range can be made using the chromium reticle (also called mask blanks) on the market.

[0107]

A chromium reticle usually has a thick chromium layer of around 100 nm formed on a quartz substrate by vapor deposition. The standard thickness of a quartz substrate is 2.286 mm, 3.048 mm, 4.572 mm, or 6.35 mm.

[0108]

The slit width 2D is better when narrower, as is described earlier in the description, and even though the slit width is very narrow in the same manner as the embodiment, in the case when a photo multiplier is used as the optical sensor 24, it is

possible to detect the light amount (light intensity) by decreasing the scanning velocity and taking time for measurement. In actual, however, since the scanning velocity of the aerial image measurement has fixed limitations from the aspect of throughput, if the slit width 2D is too narrow the light amount transmitting the slit 22 decreases too much, thus measurement becomes difficult.

[0109]

From the information the inventor acquired by simulations and experiments, or the like the optimum value of the slit width 2D was confirmed to be around half the limit of resolution pitch (pitch of the L/S patterns) of the exposure apparatus. The details on this will be described later.

[0110]

As is obvious from the description so far, in this embodiment, the aerial image measurement unit is made up of the illumination optical system 10, the aerial image measurement unit 59 (including the slit plate 90 and the optical sensor 24), the wafer stage WST, and the main controller 20. In addition, the processing unit, which is a part of the aerial image measurement unit, is configured of the main controller 20.

[0111]

The aerial image measurement unit and the aerial image measurement method as described above is used, for example, on a. detecting the best focus position, b. detecting the image forming position of the pattern image, and c. baseline measurement of the alignment microscope ALG.

[0112]

Since item c. baseline measurement of the exposure apparatus 100 in this embodiment has already been explained, following will be a description of item a. detecting the best focus position and item b. detecting the image forming position of the pattern image, referring to working examples.

Detection of the Best Focus Position

This detection of the best focus position is used for purposes such as: A. detecting the best focus position of the projection optical system PL and detecting the best image forming plane (image plane), and B. the spherical aberration measurement.

[0113]

FIG. 7 to FIG. 12 show the image forming simulation results that correspond to the case when an aerial image of a L/S mark having a 50% duty ratio and a line width of 0.2 μm measured with the aerial image measurement method described above. The conditions of this simulation are; illumination light wavelength 248 nm, N.A. of the projection optical system 0.68, illumination coherence factor σ=0.85, and the slit width 2D=0.3 μm. These conditions are close to the conditions B in Table 1.

In FIG. 7 to FIG. 12, the horizontal axis shows the Y position (μm) of the slit, and the vertical axis shows the light intensity (energy value).

[0114]

FIG. 7 shows the simulation results at the best focus position. In FIG. 7, the waveform P2 indicated by the solid line is an aerial image of L/S marks with the line width of 0.2 μm, which corresponds to i(x) in equation (1). The waveform P3 indicated by the dotted line is the light intensity signal obtained by scanning the slit (aerial image measurement) that correspond to m(x) in equation (1).

[0115]

FIG. 8 shows the aerial frequency component when Fourier Transform is performed on the intensity signal P3 in FIG. 7, that is, on m(x), along with the original intensity signal P3. In FIG. 8, the waveform P4 indicated by the broken line is a zero order frequency component, whereas, the waveform P5 indicated by the dashed-dotted line is a first order frequency component, the waveform P6 indicated by the dashed-double-dotted line is a second order frequency component, and the waveform P7 indicated by the solid line is a third order frequency component. In FIG. 8, waveforms P4 to P7 are shown raised by 1.0, so that they are made distinguishable.

[0116]

FIG. 9 shows the simulation results when the position is defocused by 0.2 μm from the best focus position. In FIG. 9, the waveform P2 indicated by the solid line is an aerial image of L/S marks with the line width of 0.2 μm, which corresponds to i (x) in equation (1), and the waveform P3 indicated by the dotted line is the light intensity signal obtained by scanning the slit (aerial image measurement) that correspond to m(x) in equation (1).

[0117]

FIG. 10 shows the aerial frequency component when Fourier Transform is performed on the intensity signal P3 in FIG. 9, along with the original intensity signal P3. In FIG. 10, the waveform P4 indicated by the broken line is a zero order frequency component, whereas, the waveform P5 indicated by the dashed-dotted line is a first order frequency component, the waveform P6 indicated by the dashed-double-dotted line is a second order frequency component, and the waveform P7 indicated by the solid line is a third order frequency component. In FIG. 10, waveforms P4 to P7 are shown raised by 1.0, so that they are made distinguishable.

[0118]

FIG. 11 shows the simulation results when the position is defocused by 0.3 μm from the best focus position. In FIG. 11, the waveform P2 indicated by the solid line is an aerial image of L/S marks with the line width of 0.2 μm, which corresponds to i (x) in equation (1), and the waveform P3 indicated by the dotted line is the light

intensity signal obtained by scanning the slit (aerial image measurement) that correspond to m(x) in equation (1).

[0119]

And, FIG. 12 shows the aerial frequency component when Fourier Transform is performed on the intensity signal P3 in FIG. 11, along with the original intensity signal P3. In FIG. 12, the waveform P4 indicated by the broken line is a zero order frequency component, whereas, the waveform P5 indicated by the dashed-dotted line is a first order frequency component, the waveform P6 indicated by the dashed-double-dotted line is a second order frequency component, and the waveform P7 indicated by the solid line is a third order frequency component. In FIG. 12, waveforms P4 to P7 are shown raised by 1.0, so that they are made distinguishable.

[0120]

As is obvious when comparing FIG. 7 and FIG. 9, the shape of the image is obviously ruined due to the defocus of 0.2 μm. In addition, when comparing FIG. 9 and FIG. 11, it can be seen that the shape of the image is obviously further ruined when the defocus amount increases.

[0121]

In addition, when the light intensity signal P3 is divided into a frequency component as is described above, various signal processing can be easily performed. For example, when focusing on contrast, which is the amplitude ratio of the first order frequency component P5 and the zero order frequency component P4, in other words, the first order/zero order amplitude ratio, the contrast in the case of the best focus position as is shown in FIG. 8, is 0.43. Also, the contrast in the case of defocus by 0.2 μm from the best focus position as is shown in FIG. 10, is 0.24μm. And, the contrast in the case of defocus by 0.3 μm from the best focus position as is shown in FIG. 12, is 0.047.

[0122]

As can be seen, the contrast, which is the first order/zero order amplitude ratio, changes sensitively depending on the focus position; therefore, it is convenient to set the best focus position from the intensity signal. That is, it is possible to detect the best focus position, by obtaining the focus position where the contrast being the first order/zero order amplitude ratio is at a maximum.

[0123]

Thus, in this embodiment, the best focus position of the projection optical system PL is detected in the following manner.

[0124]

On detecting the best focus position, L/S marks with a duty ratio of 50% on the that has a line width of 0.2 μm on the wafer (1μm on reticle) arranged within the measurement article (for convenience, refer to reticle R') are used as the measurement

pattern PM. The detection of the best focus position, is to be performed under the same conditions as the simulation described above.

[0125]

First of all, the reticle loader (not shown in figures) loads the reticle R' onto the reticle stage RST. The main controller 20 then moves the reticle stage RST so as to make the measurement pattern PM on the reticle R' almost coincide with the optical axis of the projection optical system PL.

[0126]

Next, the main controller 20 controls and drives the movable reticle blind 12 such that the illumination light IL is irradiated only on a measurement pattern PM portion. In this state, the main controller 20 irradiates the illumination light IL onto the reticle R', and as is described earlier, the aerial image measurement of the measurement pattern PM is performed similarly as above, based on the slit-scan method using the aerial image measurement unit 59 while scanning the wafer stage WST in the X-axis direction. The main controller 20 repeats the aerial image measurement a plurality of times, while changing the Z-axis position of the slit plate 90 (that is, the Z position of the wafer stage WST) in predetermined steps, and stores the light intensity signal (photoelectric conversion signal) each time in memory.

[0127]

Then, the main controller 20 calculates the contrast, which is the amplitude ratio of the first order frequency component and the zero order frequency component of the plurality of light intensity signals that are respectively Fourier transformed, based respectively on the plurality of light intensity signals (photoelectric conversion signals) obtained by the repeated measurements. And, the main controller 20 detects the Z position of the wafer stage WST (that is, the position of the slit plate 90 in the Z-axis direction) that corresponds to the light intensity signal where the contrast becomes maximum, and sets the position (focus amount) as the best focus position of the projection optical system PL. As is previously described, since the contrast changes sensitively according to the focus position, the best focus position of the projection optical system PL can be accurately and easily measured (set).

[0128]

The amplitude of the frequency component of a high order, in the second order and above, is small in general, therefore, there are some cases when the amplitude with respect to electrical noise and optical noise cannot be sufficiently detected. If there is no problem in the S/N (signal/noise) ratio, however, the best focus position can be obtained also by observing the amplitude ratio of the frequency component of the high order. The L/S mark, which is the measurement mark pattern, is preferably a pattern with an equal line and space width having a duty ratio of 50%, but it is possible to use other marks that have a duty ratio other than 50%. According to the

information obtained by the inventor from the results of experiments and the like, it has become clear that preferable results can be obtained when the arrangement period of the line pattern of the L/S marks, in other words, the mark pitch P_M is about the level of the following equation (3).

[0129]

$P_M=\lambda/N.A.\times(1\sim1.2)$ (3)

It is not limited to the method using the contrast as described above. The best focus position can be detected by a method detecting the Z position (focus position) where the differential value of the light intensity signal P (m(x) in equation (1)) is maximum.

[0130]

In addition, the detection of the image plane shape of the projection optical system PL can be performed in the following manner.

[0131]

In addition, in the case of detecting the image plane shape using a reticle, a measurement reticle R1 on which measurement pattern PM_1 to PM_n that have the same size and same period as the measurement pattern PM are formed within the pattern area PA is used, as is shown as an example in FIG. 13.

[0132]

Firstly, the reticle R1 is loaded onto the reticle stage RST by the reticle loader (not shown in figures). The main controller 20 then moves the reticle stage RST, so that the measurement pattern PM_k located at the center of the reticle R1 almost coincides with the optical axis of the projection optical system PL. And, the main controller 20 drives and controls the movable reticle blind 12 so that the illumination light IL is irradiated only on the portion of the measurement pattern PM_1 and sets the illumination area. In this state, the main controller 20 irradiates the illumination light IL on the reticle R1, and likewise with the previous description, aerial image measurement of the measurement pattern PM_1 and detection of the best focus position of the projection optical system PL are performed using the aerial image measurement unit 59 based on the slit-scan method, and the results stored in the internal memory unit.

[0133]

When the detection of the best focus position using the measurement pattern PM_1 is completed, the main controller 20 then drives and controls the movable reticle blind 12 to set the illumination area so that the illumination light IL is irradiated only on the portion of the measurement pattern PM_2. In this state, similar as above, aerial image measurement of the measurement pattern PM_2 and detection of the best focus position of the projection optical system PL are performed based on the slit-scan method, and the results are stored in the internal memory unit.

[0134]

Subsequently, the main controller 20 repeatedly performs measurement of the aerial image of the measurement patterns PM_3 to PM_n and detection of the best focus position of the projection optical system PL, while changing the illumination area described above.

[0135]

And, based on each best focus position Z_1, Z_2, . . . , and Z_n, a predetermined statistical processing as obtained above is performed to calculate the image plane shape of the projection optical system PL.

[0136]

The image plane of the projection optical system PL, that is, the best image forming plane, is a plane consisting of a group of best focus points in innumerable points where the distance from the optical axis is different (that is, innumerable points where the so-called image height differs). Therefore, by the method described above, the image plane shape can be obtained both easily and accurately.

[0137]

Thus, as is described, item A. detecting the best focus position of the projection optical system PL and detecting the best image forming plane (image plane) which was previously referred to can be achieved.

[0138]

Also, spherical aberration measurement of the projection optical system PL can be performed in the following manner.

[0139]

In addition, in the case of detecting the spherical aberration, a measurement reticle R2 is used that has two measurement patterns PM1 and PM2 arranged at a predetermined interval in the Y-axis direction formed around the center in the X-axis direction within the pattern area PA, as shown in FIG. 14. The measurement pattern PM1 is a L/S pattern that has the same size and same period as the first L/S mark of measurement pattern PM referred to earlier. And the measurement pattern PM2 is a L/S pattern of the same size as the measurement pattern PM1 but has a period of a different line pattern (for example, around 1.5-2 times wider than the period (mark pitch) of the measurement mark PM1) arranged in the X-axis direction.

[0140]

To begin with, the reticle R2 is loaded onto the reticle stage RST by the reticle loader (not shown in figures). The main controller 20 then moves the reticle stage RST, so that the measurement pattern PM1 formed on the reticle R2 almost coincides with the optical axis of the projection optical system PL. And, the main controller 20 drives and controls the movable reticle blind 12 so that the illumination light IL is irradiated only on the portion of the measurement pattern PM1 and sets the

illumination area. In this state, the main controller 20 irradiates the illumination light IL on the reticle R2, and likewise with the previous description, aerial image measurement of the measurement pattern PM1 and detection of the best focus position of the projection optical system PL are performed using the aerial image measurement unit 59 based on the slit-scan method, and the results stored in the internal memory unit.

[0141]

When the detection of the best focus position using the measurement pattern PM1 is completed, the main controller 20 then moves the reticle stage RST a predetermined distance in the +Y direction so that the illumination light IL is irradiated on the portion of the measurement pattern PM2 . In this state, similar as above, aerial image measurement of the measurement pattern PM2 and detection of the best focus position of the projection optical system PL are performed based on the slit-scan method, and the results are stored in the internal memory unit.

[0142]

Thus, the best focus position Z_1 and Z_2 are obtained in this manner, and based on the difference, the spherical aberration of the projection optical system PL is obtained by calculation.

[0143]

The spherical aberration is one of an aperture aberration of the optical system, and is a phenomenon where in the case beams having various types of apertures from the object point of the optical axis are incident on the optical system the corresponding image point is not formed at one point. Accordingly, the detection of the best focus position in the optical axis of the projection optical system can be repeatedly performed on a plurality of L/S patterns having different pitches, and the spherical aberration can be easily obtained by calculation based on the difference of the best focus position corresponding to each pattern. In this case, it is substantially necessary for the measurement accuracy of the difference of the best focus position to be around $3\sigma<20$ nm.

[0144]

Detection of the Image Forming Position of the Pattern Image

The respective purposes for detecting the image forming position of the pattern image are as follows: C. measuring the magnification and distortion of the projection optical system, D. measuring the coma aberration of the projection optical system, E. measuring the telecentricity (illumination telecentricity) of the projection optical system.

[0145]

The measurement patterns (the marks subject to measurement) differ depending on the purpose of measurement. Table 2, is a classification according to

each purpose. Since it is preferable for the measurement result of the image forming characteristics of the projection optical system based on aerial image measurement to basically match the measurement result of the image forming characteristics by the exposure method previously described, in Table 2, the aerial image measurement mark (aerial image measurement pattern) is indicated, along with the exposure measurement mark.

[0146]

[TABLE 2]

	Exposure Measurement Mark	Aerial Image Measurement Mark
C Projection Lens Magnification + distortion Measurement	Box in Box Mark, Large L/S Mark	Box in Box Mark, Large L/S mark
D Projection Lens Coma Aberration Measurement	Line in Box Mark, L/S Mark	Line in Box Mark, L/S mark, Large and Small L/S Mark
E Illumination Telecentricity Measurement	Box in Box Mark, Large L/S Mark	Box in Box Mark, Large L/S mark

[0147]

Following is a description on the magnification and the distortion measurement of the projection optical system PL. When the magnification and the distortion measurement of the projection optical system PL, for example, as is shown in FIG. 15, a measurement reticle R3 is used. On the reticle R3, measurement pattern BM_1-BM_5 which is composed of square mark is formed at a total of five points, of 150 μm (30 μm on the surface of a wafer with a 1/5 magnification) in the center and in the four corners of the pattern area PA. Further, in this case, on the slit plate 90 which constitutes the aerial image measurement unit 59, as shown in FIG. 16, light, passing through any one of the slit 22a of the predetermined width W and length L extending to X-axis direction and the slit 22b of the predetermined width W and length L extending to Y-axis direction, are formed, light passing through any of slits 22a, 22b can be photodetected by the photodetection optical system and light sensor 24 (or light guide portion and photodection portion of FIG. 3) in the inside of wafer stage WST. Herein, for example, W is 0.3μm and L is 25μm.

[0148]

Firstly, the reticle R3 is loaded onto the reticle stage RST by the reticle loader (not shown in figures). Then, the main controller 20 moves the reticle stage RST so that the center of the measurement pattern BM_1 located in the middle of the reticle R3 almost coincides with the optical axis of the projection optical system PL. Next, the main controller 20 controls and drives the movable reticle blind 12 to set the illumination area, so that the illumination light IL illuminates only a rectangular area portion including the measurement pattern BM_1, the area being one size larger than

the measurement pattern BM_1. In this state, the main controller 20 irradiates the illumination light IL on the reticle R3. Thus, the aerial image BM_1' of the measurement pattern BM1, that is almost square 30μ pattern is formed as shown in FIG. 16.

[0149]

In this state, the main controller 20 performs aerial image measurement of the measurement pattern PM_1 using the aerial image measurement unit 59 while wafer stage WST is scanned to X-axis direction, as indicated by arrow A in FIG.16. The light intensity signal m(x) obtained by the measurement is stored in memory. Then, in the main controller 20, the image forming position of the measurement pattern PM_1 is obtained by known phase detection method, based on the obtained light intensity signal m(x). Herein, as the phase detection method, for example the light intensity signal m(x) is Fourier-transformed to obtain first frequency component (regard as sine wave). The first frequency component is multiplied by sine wave based on the same frequency, for example the sum of a first period is calculated. The first frequency component is multiplied to cosine wave based on the same period as the component, for example the sum of a first period is calculated. There can be used general method such that quotient is obtained by dividing the obtained sum each other, inverse tangent (arc tangent) of the quotient is calculated, and thereby phase difference to reference signal of the first frequency component is obtained, and X-position x_1 of the measurement pattern PM_1 is obtained based on the phase difference.

[0150]

The main controller 20 performs the aerial image measurement of the measurement pattern PM_1 using the aerial image measurement unit 59 while the wafer stage WST is scanned in the Y-axis direction, and the light intensity signal m(y) obtained by the measurement is stored in a memory. Further, by the phase detection method as described above, Y-position y_1 of the measurement pattern PM_1 is obtained. Then, the main controller 20 corrects the positional deviation of the reticle R3 with respect to the center of the optical axis, based on the coordinate values (x_1, y_1) of the obtained measurement pattern PM_1.

[0151]

When correction of the positional deviation of the reticle R3 is completed, the main controller 20 then controls and drives the movable reticle blind 12 to set the illumination area, so that the illumination light IL illuminates only a rectangular area portion including the measurement pattern BM_2, the area being one size larger than the measurement pattern BM_2. In this state, likewise as above, the aerial image measurement and the measurement of the XY position of the measurement pattern BM_2 are performed based on the slit-scan method, and the results are stored in the internal memory unit.

[0152]

Hereinafter, similarly as above, the main controller 20 repeatedly performs the aerial image measurement and the measurement of the XY position of the measurement patterns BM_3-BM_5, while changing the illumination area described above.

[0153]

And, based on the coordinate values (x_2, y_2), (x_3, y_3), (x_4, y_4), and (x_5, y_5) of the measurement mark patterns BM_2 to BM_5 obtained from the measurements, a predetermined calculation is performed to obtain at least either the magnification or the distortion of the projection optical system PL.

[0154]

Distortion refers to an aberration of the projection optical system PL where an image of a line originally straight turns out to be a distorted image, and due to this distortion, the mark image formed on the image plane is shifted (laterally) from the predetermined position, similar to the case when there is a magnification error.

[0155]

Accordingly, by the measurement method of magnification and distortion described above, the positional shift of the aerial image of each measurement pattern projected at different positions within the image field of the projection optical system PL can be respectively obtained with good accuracy using the phase detection method. As a consequence, at least either the distortion or the magnification can be measured with good accuracy.

[0156]

There are cases, however, when a sufficient measurement accuracy cannot be obtained when slit-scanning a single 30 square μm pattern image BM_n' (n=1, 2,......, 5) since the image only has two edges. In such a case, the measurement pattern (for convenience, "CM_1 to CM_5 ") is composed of an L/S pattern large enough so that it is hardly affected by the coma aberration, for example L/S pattern having a line width of 5 μm or over (the aerial image will be an L/S pattern image having a line width of 1 μm). The measurement pattern may use the formed reticle, instead of the measurement pattern BM_1 to BM_5,. In FIG. 17, when the aerial image measurement is performed using these reticles, there represents the state where the aerial image CM_n' (n=1, 2,......, 5) of the measurement patterns CM_1 to CM_5 is formed on the slit plate 90.

[0157]

In the description above, the positional shift of the aerial image of the measurement pattern is measured by the phase detection method. The present invention is not limited to this, however, and aerial image measurement based on the slit-scan method can be repeatedly performed on the aerial image of the measurement

pattern (BMn or CMn) projected at different positions within the image field of the projection optical system PL. And, based on the intersection point of each of a plurality of light intensity signals m(x) (photoelectric conversion signals) obtained by the measurements and a predetermined slice level, the position of the aerial image (BMn' or CMn') (edge position) corresponding to each photoelectric conversion signal can be respectively calculated. And, at least either the distortion or the magnification of the projection optical system PL may be obtained, based on the calculation results. In such a case, according to the edge detection method using the slice method, the position of the aerial image (BMn' or CMn') projected at different positions within the image field of the projection optical system PL can respectively be obtained with good accuracy, and as a result, at least either the distortion or the magnification can be measured with good accuracy. In this case, when each light intensity signal is processed in binary at the predetermined slice level and the slice level is set appropriately, for example, as can be surmised from the relation between the waveform P2 and P3 in FIG. 7, this state becomes equivalent to measuring the edge position of the resist image that can be actually obtained by exposure.

[0158]

With the current exposure apparatus, distortion (including magnification) control of the projection optical system is performed in the following manner, using a reference wafer. Reference wafer, here, refers to a wafer, on which an outer BOX mark of 30 square μm is transferred within the exposure area by the projection optical system, developed, and etched, and after the etching process the position of the edge of the outer BOX mark is measured in advance with equipments such as the optical interferometric coordinate measurement unit. And, when distortion of the exposure apparatus is measured, a resist image of a 10 square μm inner BOX mark is exposed in the center of the outer BOX mark of 30 square μm made in the etching process, and the positional relation between the two marks is measured with the registration measurement unit and the like.

[0159]

Accordingly, if distortion measurement is performed, by detecting the aerial image of the 10 square μm BOX mark on the wafer (on the image plane) with the edge detection method, the influence of the coma aberration becomes similar to when distortion measurement is performed as above using the reference wafer. Therefore, a relative difference does not occur. This allows distortion to be measured from the aerial image, with the accuracy equivalent to distortion measurement described above using the reference wafer.

[0160]

To achieve this measurement, consideration can be made of forming an inner BOX mark of 50 square μm (10 square μm on the wafer) on the device reticle or the

reticle mark plate referred to earlier. However, the mark of 10 square μm cannot be formed on the wafer because of dishing occurring in the recent CMP process.

[0161]

Therefore, after diligent study, the inventor reached a conclusion that the aerial image measurement is to be performed using a BOX mark of 10 square μm on the wafer subdivided into strips in the non-measurement direction (the length not necessarily being 10 μm) (the mark hereinafter referred to appropriately as an "artificial BOX mark"). The reason for this, is because the artificial BOX mark is a type of the so-called L/S pattern, and if aerial image measurement is performed based on the slit-scan method by scanning the aerial image measurement unit in the direction perpendicular to the periodic direction, the signal waveform that can be obtained turns out to be similar to the signal waveform obtained from the aerial image of the BOX mark.

[0162]

The inventor performed distortion measurement of the projection optical system PL by the edge detection method in the procedure previously described, using a measurement reticle R3' on which an artificial BOX pattern subdivided in strips in regard to the X direction is formed, instead of using the measurement patterns BM_1-BM_5 of the measurement reticle R3 shown in FIG. 15. As a consequence, it was confirmed that the Y position of each measurement pattern was the same as the Y position of the measurement pattern BMn. According to this confirmation, distortion measurement can be performed by preparing a measurement reticle on which an artificial BOX pattern subdivided in strips in regard to the Y direction and an artificial BOX pattern subdivided in strips in regard to the X direction are formed, and by relatively scanning the respective measurement pattern with the slit 22a and 22b.

[0163]

FIG. 18 shows an example of a mark block (300 square μm) on which the artificial BOX mark pattern subdivided in strips in regard to the Y direction, the artificial BOX mark pattern subdivided in strips in regard to the X direction described above, and other measurement patterns are formed. In FIG. 18, the marks MM1 and MM2 are, for example, magnification measurement patterns made up of five 5 μm L/S marks, the marks MM3 and MM4 are, for example, focus measurement patterns made up of twenty-nine 1 μm L/S marks, and the marks MM5 and MM6 are, for example, artificial-BOX patterns made up of eleven 2.5 μm L/S marks. This mark block, in FIG. 18, is formed, for example, on the device reticle or the reticle fiducial mark plate. Incidentally, on subdivision of the artificial-BOX mark, it is preferable for the L/S mark to be around 2.5 μm or below (the L/S to be around 0.5 μm or below on the wafer).

[0164]

Next, the measurement method of the coma aberration of the projection optical system will be described. The following two methods are typical in the measurement of the coma aberration, the first method of using the L/S mark as the measurement mark pattern, and the second method of using the Line in Box mark as the measurement mark pattern.

[0165]

The First Method

In the case of measuring the coma aberration by exposure, the method using the line width abnormal value of the small L/S mark image around the limit of resolution is known. The line width abnormal value, here, is a value serving as an indicator to indicate the asymmetrical degree of the resist image formed by exposure. For example, in the case of a resist image of a 0.2 μm L/S mark (design value) as is shown in FIG. 19, the line width abnormal value A can be defined as in the following equation (4), using the line widths L1 and L5 of line pattern on both edges.

[0166]

[Formula 3]

$$A = \frac{L1 - L5}{L1 + L5} \quad \cdots (4)$$

[0167]

The desirable performance of the projection optical system (the projection lens) is for the value A to normally be less than 3%.

[0168]

The line width abnormal value of the L/S pattern image can also be directly measured on aerial image measurement. In this case, the edge detection method by the slice method may be used, however, on setting the slice level, a simple resist image simulation of processing the light intensity signal corresponding to the aerial image in binary at an appropriate threshold value (threshold level) to make the processed light intensity signal become closer to the line width of the resist image is preferably performed. Accordingly, it is desirable to set the threshold value as the slice level.

[0169]

The measurement method of the coma aberration by the line width abnormal value is explained in the following description. When measuring the coma, for example, as is shown in FIG. 20, a measurement reticle R4 is used. On the reticle R4, measurement mark patterns DM_1-DM_5 are formed at a total of five points, in the center and in the four corners of the pattern area PA. As the measurement mark patterns DM_1-DM_5, an L/S pattern having a line width of 1 μm (0.2 μm on the wafer surface) with a 50% duty ratio and a periodicity in the X-axis direction, is used.

Further, in this case, the slit plate 90 which constitutes the aerial image measurement unit 59 and the aerial image measurement unit 59, or the like are constituted in the same manner as measurement for magnification and distortion described above.

[0170]

In this case, in the procedure same as the magnification and distortion measurement previously described, the main controller 20 performs reticle alignment and aerial image measurement and obtains the light intensity signal m(x), which corresponds to the aerial image (DM_2'-DM_5') of the measurement patterns DM_2-DM_5.

[0171]

And the intersection points of each light intensity signal m(x) obtained and a predetermined slice level are respectively obtained, and from the X coordinate of the intersection points obtained, the line width of each line of the respective aerial images DM_2'-DM_5' is obtained, and based on the line width the line width abnormal values are respectively calculated, based on equation (4). And, the coma aberration of the projection optical system PL is obtained based on the calculation result.

[0172]

The coma aberration, is an aberration of the lens due to different magnifications in various zones of the lens, and occurs at portions far from the main axis within the image field of the projection optical system PL. Accordingly, at a position far from the optical axis, the line width of each line pattern becomes different depending on the coma aberration in the aerial image of the L/S pattern. Therefore, with the method described above by using the slice method and detecting the line width abnormal value of each line pattern with the edge detection method, it becomes possible to measure the coma aberration with high accuracy, in a simple manner.

[0173]

In the case each measurement pattern DM_1-DM_5, for example, is a single L/S pattern including five line patterns, and the measurement accuracy of the line width abnormal value is not sufficient enough, a combined mark pattern that has an arrangement of a plurality of L/S patterns with five lines combined in a predetermined period may be used as the measurement pattern. In FIG. 21 when these composite mark pattern is used as the measurement pattern (refer to EM), it is represent that the aerial image EM' of the measurement pattern EM on the slit plate 90 is formed.

[0174]

As is shown in FIG. 22, the aerial image EM' has two fundamental frequency components. That is, for example, a frequency component (a first fundamental frequency component) f1 that corresponds to the pitch of each line pattern of the photoelectric conversion signal and has a 0.4 μm pitch, and a frequency component f2 that corresponds to the repetition period of each L/S pattern (the arrangement pitch of a mark group, which consists of five lines), such as a pitch of 3.6 μm, in other words,

a second fundamental frequency component corresponding to the entire width of each L/S pattern.

[0175]

Accordingly, the main controller 20 may perform reticle alignment and aerial image measurement in the procedure same as the magnification and distortion measurement previously described. And, when the light intensity signal m(x) corresponding to the aerial image EM_2'-EM_5' of the measurement pattern EM_2-EM_5 is obtained, the main controller 20 may calculate the phase difference between the first fundamental frequency component described above and the second fundamental frequency component of each light intensity signal based on the phase detection method, and based on the calculation results may obtain the coma aberration of the projection optical system PL.

[0176]

When the width of the pattern subject to aerial image measurement in the scanning direction is narrower, the influence of the coma aberration is more apparent. Therefore, the influence of coma aberration on the aerial image of each line pattern of the L/S line pattern is different from the influence of coma aberration on the aerial image of a pattern when the entire L/S pattern is regarded as a single pattern. Accordingly, the phase difference of the first fundamental frequency component corresponding to the pitch of each line pattern of the photoelectric conversion signals and the second fundamental frequency component corresponding to the entire width of the L/S pattern can be calculated. And, based on the calculation result, according to the method described above of obtaining the coma aberration of the projection optical system, the coma aberration of the projection optical system PL can be obtained with high accuracy with the phase detection method. In this case, it is preferable to set the ratio of the arrangement pitch of the mark (0.4 μm in the example above) and the arrangement pitch of the mark group consisting of five lines mark (3.6 μm in the example above) multiplied in integer, from the signal processing point of view.

[0177]

The Second Method

The second method of measuring the coma aberration will be described next. In this method, as shown in FIG. 23A, a measurement reticle R5 is used. On the reticle R5, measurement patterns FM_1-FM_5 are formed at a total of five points, in the center and in the four corners of the pattern area PA. As the measurement patterns FM_n(n=1,2,...5), mark pattern referred to as "Line in Box Mark" is used which is shown by magnification in FIG. 23B. As shown in FIG. 23B, the mark pattern is a mark of a square-shaped pattern with a side length D1 (for example, D1=150 μm), which has a square-shaped space pattern (width D3) that is concentric with the square-

shaped pattern and with a side length D2 (for example, D2=100 μm) formed in the interior. When the measurement pattern FMn is exposed on the wafer and is developed, a narrow groove of 20 square μm is formed at the same time in the center of a resist mark of 30 square μm. The width of the narrow groove is preferably around (λ/N.A.)/2 or below, therefore, D3 is preferably around 4 times or below. For example, D3 may be 0.5 μm.

[0178]

When the image of the mark measurement pattern FMn is formed with a projection optical system having a coma aberration, since the lateral shift of the narrow line is greater than the wide line, the narrow groove turns out to be eccentric and loses its symmetry. Accordingly, by measuring the eccentric amount of the narrow groove, in other words, the degree of the symmetry lost, the influence of the coma aberration can be acknowledged.

[0179]

Further, in this case, the slit plate 90 which constitutes the aerial image measurement unit 59 and the aerial image measurement unit 59 are constituted in the same manner as magnification and distortion measurement described above.

[0180]

In this case, in the procedure same as the magnification and distortion measurement previously described, the main controller 20 performs reticle alignment and aerial image measurement and obtains the light intensity signal m(x), which corresponds to the aerial image (refer to FM_2'-FM_5') of the measurement patterns FM_2-FM_5.

[0181]

And based on the intersection point of each light intensity signal and the predetermined slice level, the symmetric shift of the aerial image FM_2'-FM_5' of measurement pattern is calculated, and the coma aberration of the projection optical system PL is obtained based on the calculation results.

[0182]

In this manner, with the edge detection method using the slice method, the symmetric shift of the aerial image of the measurement pattern FM_2-FM_5 can be calculated, and with the method described above of obtaining the coma aberration of the projection optical system PL based on the calculation results, the coma aberration of the projection optical system PL can be obtained with high accuracy.

[0183]

In the case described above, the situation may occur where the slit in the non-measurement direction interferes with the aerial image, due to the arrangement of the slit 22a and 22b on the slit plate 90. In such a case, instead of using the measurement mark FMn as above, a linear mark pattern laterally symmetric that has, for example, a

wide line pattern with a line width of 50 μm and a narrow line pattern with a line width of 0.5-0.75 m arranged at a predetermined interval (for example, 50 μm) in the measurement direction, and may be used as the measurement pattern.

[0184]

FIG. 24 shows the state of an aerial image GMn' of such a measurement pattern (refer to GMn) formed on the slit plate 90. In FIG. 24, D4 is 10 μm, and D5 is 0.1-0.15 μm. The coma aberration of the projection optical system PL may be detected, by detecting the light intensity signal corresponding to such an aerial image GMn' with the edge detection method using the slice method.

[0185]

The positional shift due to the effect of the coma aberration is greater in the aerial image of a line pattern having narrow width in the scanning direction (measurement direction). As a consequence, the symmetry of the aerial image of a symmetric mark pattern having various types of line patterns with different line widths arranged at a predetermined interval in the direction corresponding to the scanning direction, such as the measurement pattern (GMn), is greatly deformed, when the coma aberration becomes large.

[0186]

Thus, according to the method of detecting the symmetric shift of the aerial image GMn' described above, the coma of the projection optical system PL can be detected with high accuracy.

[0187]

In this case, also, as a matter of course, in order to improve the measurement reproduction, the aerial image HM' of the measurement pattern repeatedly arranged as in FIG. 25, may be detected.

[0188]

Next, the method of measuring the illumination telecentricity will be described.

[0189]

The illumination telecentricity is set, by measuring the changing amount of the image position that changes due to defocus. As the measurement pattern, a large mark pattern that is not affected by the coma aberration is used, likewise with the magnification and distortion measurement. In the case of the exposure method, a Box in Box Mark or a large L/S mark is used, and exposure is respectively performed at three points; the best focus position, the defocus position of around +1 μm, and the defocus position of around -1 μm. Then, the relation between the image position and the focus position is measured, and the illumination telecentricity (=(lateral shift amount of the image/defocus amount)) is calculated.

[0190]

In the case of aerial image measurement, a large mark that is not affected by the coma aberration is used, similar to the case of the exposure method, and the absolute position of the aerial image is measured at each focus position. Thus, the illumination telecentricity is calculated.

[0191]

As is described in detail so far, with the exposure apparatus 100 related to the first embodiment, the exposure apparatus 100 includes an aerial image measurement unit 59 that has a slit plate 90 which slit width is, $2D=n\cdot(\lambda/N.A.)$, $n\leq0.8$. Therefore, by performing aerial image measurement of the measurement pattern arranged on the reticle or the reticle fiducial mark plate using this aerial image measurement unit, aerial image measurement with high precision becomes possible where the image profile hardly deteriorates when converting the aerial image to the aerial image intensity signal. In this case, the signal processing system arranged downstream of the optical sensor 24 (photoconversion element) will not require a large dynamic range.

[0192]

In addition, with the exposure apparatus 100, the main controller 20 can perform aerial image measurement based on the slit-scan method using the aerial image measurement unit 59, and by using the measurement results, measurement of various image forming properties of the projection optical system PL described earlier can be performed with high precision. Therefore, for example, at the startup operation of the exposure apparatus in the factory, adjustment of the optical properties of the projection optical system PL may be performed with high accuracy based on the measurement results of image forming performance. Alternatively, With reference to distortion or magnification, the measurement is carried out periodically, and projection optical system PL based on the measurement result can correct distortion or magnification (in particular, non-scanning direction in scanning and exposure), using a correction unit (for example, Z/tilt driving unit of specific lenses elements constituting projection optical system, or adjusting internal pressure of airtight room provided between specific lenses element constituting projection optical system) of image forming property not shown. Further, the magnification in scanning direction in scanning and exposure is corrected by adjusting the scanning rate of at least reticle and wafer in scanning and exposure for example.

[0193]

As is described, with the exposure apparatus 100, for example, due to the initial adjustment of the image forming properties of the projection optical system or adjustment of the image forming properties of the projection optical system prior to starting exposure, exposure is performed using a projection optical system PL which

image forming properties are adjusted to high precision. As a consequence, the exposure accuracy can be improved.

[0194]

In addition, with the exposure apparatus 100, the main controller 20 detects the baseline amount of the alignment microscope ALG1 serving as a mark detection system with high accuracy using the aerial image measurement unit 59. Thus, by using the baseline amount and controlling the position of the wafer W during exposure or the like, it becomes possible to improve the overlay accuracy of the reticle and the wafer. From this viewpoint as well, exposure accuracy can be improved.

[0195]

In the embodiment above, the case has been described where the slit width 2D is set in consideration of both the wavelength λ of the illumination light and the numerical aperture N.A. of the projection optical system PL, however, the present invention is not limited to this.

[0196]

That is, the slit width 2D may be set in consideration of only the wavelength λ or the numerical aperture N.A. Even in the case of using an aerial image measurement unit comprising a slit plate having a slit such as this slit width 2D, likewise with the embodiment above, measurement of the aerial image (image intensity distribution) of a predetermined pattern based on the slit-scan method is possible with high precision.

[0197]

Next, the setting of the slit width (2D) will be further described. As an example, a suitable setting method of the slit width will be described, referring to the case of focus measurement.

[0198]

As is previously described, the measurement of the best focus position of the projection optical system is obtained, by repeating the aerial image measurement of the measurement pattern a plurality of times while changing the position of the slit plate 90 in the Z-axis direction (optical axis direction) based on the slit-scan method, and detecting the Z position (the Z coordinate of the contrast peak) of the slit plate 90 where the contrast being the amplitude ratio of the light intensity signal (first order/zero order) obtained by the aerial image measurement is at a maximum.

[0199]

Usually, when the best focus is detected, the slit plate 90 is changed at a pitch interval of 0.15μm in approximately 15 stages (steps).

[0200]

An example of best focus detection referred to above will now be described, using FIG. 26. FIG. 26 shows the measurement values of the contrast (the mark x in FIG. 26) obtained at 13 points, when the slit plate 90 is changed in the Z-axis direction in 13 stages (steps), with the horizontal axis as the Z-axis. Based on the contrast measurement values at the 13 points indicated with the mark x in FIG. 26, the approximation curve C of around the fourth order is obtained by the least squares method. The intersection points of the approximation curve C and an appropriate threshold value (threshold level) SL is obtained, and the midpoint of the distance between the intersection points =2B, is set as the Z coordinate value corresponding to the best focus.

[0201]

FIG. 27 shows a line graph similar to FIG. 26. In FIG. 27, however, the vertical axis indicates the amplitude (or the first order, which will be described later) of the first order frequency component. The focus detection accuracy will now be considered, when the range of WZ (=step pitch x the number of data) in FIG. 27 is fixed.

[0202]

(1) In the case that shot noise is dominant, when the amplitude of the first component is expressed as S, the shot noise is proportional to $S^{1/2}$. The average tilt of the curve related to the amplitude of the first frequency component Z (simply refer to the first component) is inversely proportional to the depth of focus (DOF), therefore, when the noise of the amplitude of the respective first components that randomly fluctuates the data in the Z direction is expressed as noise N, then the relationship can be indicated as follows,

$$N \propto S^{1/2} \cdot DOF \propto \lambda \cdot S^{1/2} / (N.A.)^2 \qquad (5)$$

In this case, N.A. is the numerical aperture of projection optical system.

[0203]

So, when the line width of the subject pattern is set as P, since $P \propto \lambda / N.A.$, the relation in the following equation (6) is valid.

$$S / N \propto (N.A.)^2 \cdot S^{1/2} / \lambda \propto \lambda \cdot S^{1/2} / P \qquad (6)$$

S/N, in this case, is the S/N ratio, which is the ratio of the amplitude of the first component and the noise amplitude.

[0204]

(2) In the case that dark noise is dominant, dark noise is not dependent on the amplitude S of the first component. The average tilt of the curve related to the amplitude of the first component Z is inversely proportional to the depth of focus (DOF), therefore, when the noise of the amplitude of the respective first components that randomly fluctuates the data in the Z direction is expressed as noise N, then the relationship can be indicated as follows.

$N \propto DOF \propto \lambda / (N.A.)^2$ (7)

[0205]

Accordingly, when the line width of the subject pattern is set as P, the relation in the following equation (8) is valid.

$S / N \propto (NA)^2 \cdot S/\lambda \propto \lambda \cdot S/P$ (8)

[0206]

When the slit width (2D) is optimized with the equations (6) and (8), if the wavelength and the pitch of the subject pattern are set, attention is required only on the amplitude S of the first component, and it is obvious that the S/N ratio is proportional to the 0.5th-1st power of the first order amplitude S, depending on the noise properties.

[0207]

In FIGS. 28A to 31B, simulation results to obtain a suitable range of the slit width (2D) are exemplified. Of these figures, FIG. 28A, FIG. 29A, FIG. 30A, and FIG. 31A are results under the condition of N.A=0.68, λ=248 nm, and σ=0.85. Whereas, FIG. 28B, FIG. 29B, FIG. 30B, and FIG. 31B are results under the condition of N.A.=0.85, λ=193 nm, and σ=0.85.

[0208]

FIG. 28A and FIG. 28B show the S/N ratio related to focus detection, in the case of applying the equation (6) when assuming an example of using a photo multiplier. In FIG. 28A, the solid line (•), the broken line (□), and the dotted line (Δ) respectively indicate the case when the L/S pattern is used having the line width L respectively of 200 nm, 220 nm, and 250 nm, and the duty ratio of 50% in all cases, as the measurement mark. And, in FIG. 28B, the solid line (•), the broken line (□), and the dotted line (Δ) respectively indicate the case when the L/S pattern is used as the measurement mark, that have the line width L respectively of 120 nm, 130 nm, and 140 nm, and the duty ratio of 50% in all cases.

[0209]

FIG. 29A and FIG. 29B indicate the contrast that respectively correspond to FIG. 28A and FIG. 28B. The contrast becomes larger, when the slit width becomes smaller. Since the amplitude of zero order is proportional to the slit width, the first order (1st Order) is the result of the contrast taken to the slit width ratio power, with 0.3 μm as a reference of the slit width ratio. The first order is proportional to the amplitude of the first component.

[0210]

FIG. 30A and FIG. 30B indicate the first order that respectively correspond to FIG. 28A and FIG. 28B.

[0211]

From FIG. 28A and FIG. 28B, consequently, it is obvious that in all wavelengths and line widths, the optimum slit width (2D) for focus detection is the length the same as half the pattern pitch (=2L). As for the pitch, the smaller the better, however, as a matter of course, it essentially has to be within the limit of resolution. Accordingly, the optimum value of the slit width is to be about half the limit of resolution pitch of the exposure apparatus.

[0212]

FIG. 31A and FIG. 31B indicate the S/N ratio related to focus detection when applying the equation (8) under the same conditions as FIG. 28A and FIG. 28B.

[0213]

Optimization of the slit width 2D will now be described, from a different point of view.

[0214]

When the slit width of the aerial image measurement unit is expressed as 2D and the intensity distribution of the aerial image i(x), then the slit transmittance intensity m(x) can be expressed as in the following equation (9) by generalizing the equation (1) previously described.

[0215]

[Formula 4]

$$m(x) = \int_{x-D}^{x+D} i(t)\,dt \quad \cdots(9)$$

[0216]

The focus detection is calculated from the zero order and first order ratio (contrast) of the intensity image of the L/S in the limit of resolution. When the intensity of the zero order component included in the intensity image of the aerial image is expressed as a, and the intensity of the first order component $b \cdot \sin(\omega_1 \cdot x)$, the slit transmittance light intensity $m_0(x)$, $m_1(x)$ observed can be expressed as in the following equations (10) and (11). ω_1, in this case, is the spatial frequency in the limit of resolution.

[0217]

[Formula 5]

$$m_0(x) = a\int_{x-D}^{x+D} dt = 2aD \quad \cdots(10)$$

[0218]

[Formula 6]

$$m_1(x) = b\int_{x-D}^{x+D} \sin(\omega_1 t)\,dt = \frac{2b}{\omega_1}\sin(\omega_1 x)\cdot\sin(\omega_1 D) \quad \cdots(11)$$

[0219]

From equation (10), it can be seen that the zero order component is simply proportional to the slit width, and as for equation (11), the first order component becomes maximum when it satisfies the conditions of the following equation (12).

[0220]

$\omega_1 D=\pi/2\cdot(2n-1)$ (12)

(provided that n=1, 2, 3,...)

[0221]

When equation (12) is satisfied, in the case $D=\pi/(2\omega_1)$ is multiplied by odd numbers, the gain of the first order component becomes maximum (the contrast becomes maximum). Therefore, when the slit width 2D is π/ω_1 multiplied by an odd number, that is, the slit width 2D is preferably half the minimum mark pitch (hereinafter referred to as "minimum half-pitch" as appropriate) multiplied by an odd number.

[0222]

In addition, the setting of the dynamic range of the electric system becomes easier when the first order component gain is high and the zero order component gain is low. So, ultimately, in the case of n=1 in equation (12), that is, when the slit width 2D is π/ω_1, in other words, when slit width 2D coincides with the minimum half-pitch, the slit width 2D is at the optimum.

[0223]

FIG. 32A and FIG. 32B respectively indicate the simulation data when the slit width 2D is of equal magnification and is of three times the minimum half-pitch. In these drawings, the solid line curve LL1 shows the intensity signal of the light transmitting the slit, the dashed-dotted line LL2 shows the differential signal of the light, and the broken line LL3 shows the aerial image strength. In these drawings, the horizontal axis shows the slit position, and the vertical axis shows the signal intensity.

[0224]

FIG. 33A and FIG. 33B respectively indicate the simulation data when the slit width 2D is five times and is seven times the minimum half-pitch. In these drawings, the solid line curve LL1 shows the intensity signal of the light transmitting the slit, the dashed-dotted line LL2 shows the differential signal of the light, and the broken line LL3 shows the aerial image strength. In these drawings, the horizontal axis shows the slit position, and the vertical axis shows the signal intensity.

[0225]

From FIG. 32A and FIG. 32B, and from FIG. 33A and FIG. 33B, it can be seen that the amplitude of the differential signal LL1 is the same. However, when the n, in the equation slit width 2D=minimum half-pitch x n, increases by 1, 3, 5, and 7, the signal processing system (the processing system arranged further downstream of

the optical sensor) obviously requires a greater dynamic range. This shows, that the slit width 2D is at the optimum when the slit width 2D coincides with the minimum half-pitch.

[0226]

In addition, when the Fourier Transform is performed on equations (1) and (2), the frequency characteristic of the averaging effect by the slit is ascertained.

[0227]

[Formula 7]

$$p(u) = \int_{-\infty}^{\infty} p(x) \cdot \exp(-2\pi ux)\,dx = 2D\frac{\sin(2\pi uD)}{2\pi uD} = 2D\frac{\sin(\omega D)}{\omega D} \quad \cdots(13)$$

[0228]

FIG. 34 shows the frequency characteristics when the slit width 2D is equal, three times, and five times the half-pitch of the limit of resolution, with ω_1 being the spatial frequency in the limit of resolution. In FIG. 34, the reference marks GF5, GF3, and GF1 respectively show the frequency characteristic line graph when the slit width is five times, three times, or equal to the minimum half-pitch. As is obvious from FIG. 34, from the aspect of stability in the gain, the slit width is at the optimum in the case the slit width coincides with the minimum half-pitch (GF1).

[0229]

The Second Embodiment

Next, the second embodiment related to the present invention will be described, based on FIG. 35 and FIG. 36. Structures and components that are identical or equivalent to the exposure apparatus 100 related to the first embodiment previously described, are designated with the same reference numerals, and the description thereabout is briefly made or is entirely omitted.

[0230]

FIG. 35 shows the arrangement of an exposure apparatus related to the second embodiment, with a part of the arrangement omitted. The exposure apparatus 110 differs from the exposure apparatus 100 only on the point that the arrangement of the alignment optical system ALG2 serving as a mark detection system is different. Therefore, hereinafter, this difference will be mainly focused in this description.

[0231]

As is shown in FIG. 35, the alignment optical system ALG2 is a laser scanning alignment sensor based on the off-axis method, arranged on the side surface of the projection optical system PL.

[0232]

The alignment system ALG2, as is shown in FIG. 35, is structured including: an alignment light source 132; a half mirror 134; a first objective lens 136; a second

objective lens 138; a silicon photodiode (SPD) 140, and the like. In this case, as the light source 132, a helium-neon laser is used. With the alignment microscope ALG2, as is shown in FIG. 35, the laser beam emitted from the light source 132 forms a laser beam spot to illuminate the alignment mark Mw on the wafer W via the half mirror 134 and the first object lens 136. The laser beam is normally fixed, and by scanning the wafer stage WST, the laser beam and the alignment mark M_W are relatively scanned.

[0233]

The scattered light generated from the alignment mark Mw is concentrated and photo-detected on the silicon photodiode SPD 140 via the first objective lens 136, the half mirror 134, and the second objective lens 138. A zero order optical filter is inserted in the alignment microscope ALG2 to create a darkfield, and the scattered light is detected only at the position where the alignment mark Mw is located. The light photo-detected by the SPD 140 is transformed into photoelectric conversion signals, which are sent to the main controller 20 from the SPD 140. In main controller 20, based on the photoelectric conversion signals and the positional information of the wafer stage WST upon detection, which is the output of the wafer interferometer 31, the coordinate position of the alignment mark Mw is calculated, in the stage coordinate system that is set by the optical axes of the interferometer.

[0234]

The baseline stability of such a stage scan type laser scanning alignment sensor is set by the stability of the beam position of the laser, the stability of interferometer, and the stability of the gain in the SPD-electric system.

[0235]

The baseline measurement of the alignment microscope ALG2 will now be described. As a premise, the reticle R is to be mounted on the reticle stage RST.

[0236]

First of all, likewise as is previously described, the main controller 20 measures the projected image of the reticle alignment mark PM formed on the reticle R using the aerial image measurement unit 59, and obtains the projection position of the reticle pattern image. That is, the reticle alignment is performed.

[0237]

Next, the main controller 20 moves the wafer stage WST, and as is shown in FIG. 36, scans the slit 22 of the aerial image measurement unit 59 with respect to the laser beam spot, simultaneously takes in the light intensity signal of the laser beam passing through the slit and the measurement values of the wafer interferometer 31, obtains the profile of the laser beam, and based on the profile, obtains the position of the beam spot. With this operation, the positional relation between the projection position of the pattern image of the reticle R and the laser spot irradiation position of

the alignment optical system ALG2, that is, the baseline amount of the alignment microscope ALG2 is obtained.

[0238]

According to the exposure apparatus 110 related to the second embodiment described so far, effects similar to the exposure apparatus 100 in the first embodiment described earlier can be obtained. Furthermore, in this case as well, the main controller 20 detects the baseline amount of the alignment microscope ALG2 using the aerial image measurement unit 59, and upon detecting the baseline amount, since the projection position of the reticle pattern image and the position of the alignment microscope ALG2 can be measured more directly by the aerial image measurement unit 59, measurement of the baseline amount becomes possible with high precision.

[0239]

The arrangement of the slit on the slit plate 90 of the aerial image measurement unit 59 is not limited to those previously described. For example, as is shown in FIG. 37A, a set of slits 22c, 22d respectively extending in the direction of 45° and 135° with respect to the X-axis, may be added to the set of slits 22a and 22b referred to earlier. As a matter of course, the slit width 2D, which is perpendicular to the longitudinal direction of the slits 22c and 22d, is set according to the same reference in the same size as the slits 22a and 22b.

[0240]

In this case, as is shown in FIG. 37A, for example, when the slit 22d is scanned with respect to the aerial image PM' in FIG. 37A while the aerial image measurement unit 59 (wafer stage WST) is being scanned in the direction indicated by the arrow C, the light intensity signal corresponding to the aerial image can be detected with high precision. In addition, as is shown in FIG. 37B, for example, when the slit 22c is scanned with respect to the aerial image PM' in FIG. 37B while the aerial image measurement unit 59 (wafer stage WST) is being scanned in the direction indicated by the arrow D, the light intensity signal corresponding to the aerial image can be detected with high precision.

[0241]

In the case of arranging the two sets of slits (22a, 22b)(22c, 22d) described above on the slit plate 90, since these slits in the respective sets are arranged apart from one another to a certain extent, as the arrangement of the photodetection optical system and the optical sensor within the wafer stage WST, the arrangement may be employed where the slit in each set can be selectively chosen by an optical or an electrical selection mechanism. To be more specific, a photodetection system, of which the optical path can be changed with a shutter, and a single photoconversion element may be combined, or a photodetection system and a photoconversion element may be respectively provided in the slits of each set.

[0242]

Following is a description on image recovery.

[0243]

From the equations (1) and (2) previously described, by the averaging of the slit scan, when the Fourier Transform is performed on the p(x) the type of spectrum is clarified in terms of spatial frequency. This is generally referred to as the instrumental function P (u). The instrumental function is expressed by equation (13), referred to earlier.

[0244]

The P_inv(u), as a filter with an inverse characteristic of the frequency characteristic in equation (13), is expressed as in the following equation (14), and when this is multiplied by the Fourier spectrum of the light intensity signal m(x) of the aerial image observed and then an inverse Fourier Transform performed, image recovery is thus performed.

P_inv(u)=1/P(u) (14)

For a complete image recovery, since the upper limit of the optical transfer function (OTF) of the incoherent image forming is 2N.A./ λ, the following equation (15) needs to be satisfied

[0245]

[Formula 8]

$$D < \frac{\lambda}{4N.A.} \quad \cdots (15)$$

[0246]

By using such a method of image recovery, it also becomes possible to recover an image profile having extremely thin isolated lines. Isolated lines include various frequency components, and when the aerial image of the isolated lines is measured at a plurality of focuses, measurement of the wavefront aberration of the lens can also be considered using these results.

[0247]

In addition, by performing image recovery on the L/S mark, which is a repetition pattern, measurement of the wavefront aberration of the discrete frequency component of the lens can also be considered.

[0248]

When aerial image measurement is performed upon these wavefront aberration measurements, it is preferable to use a unit, for example, like the aerial image measurement unit 59 in FIG. 37A, which is capable of aerial image measurement in the four directions shown in FIG. 37A.

[0249]

In each embodiment above, the case has been described when the present invention is applied to a projection exposure apparatus based on the step-and-scan method. The present invention, however, is not limited to this, and can be suitably applied to an exposure apparatus of the step-and-repeat type, which transfers a mask pattern onto a substrate when both the mask and substrate are in a stationary state, and sequentially moves the substrate with stepping operations.

[0250]

In addition, in each embodiment above, the case has been described when the present invention is applied to an exposure apparatus used for manufacturing a semiconductor. The present invention, however, is not limited to this, and can be broadly applied to, for example, an exposure apparatus for liquid crystals to transfer a liquid crystal display device pattern onto a square-shaped glass plate, or an exposure apparatus to produce a thin-film magnetic head.

[0251]

Also, in each embodiment above, the case has been described when the illumination light for exposure used, is a KrF excimer laser beam (248 nm), an ArF excimer laser beam (193 nm), or the like. The present invention, however, is not limited to this, and a g-line (436 nm), an i-line (365 nm), an F2 laser beam (157 m), a copper vapor laser, a harmonic such as a YAG laser, and the like may be used as the illumination light for exposure.

[0252]

In addition, in each embodiment above, the case has been described when the projection optical system used is a reduction system. The present invention, however, is not limited to this, and a projection optical system of an equal magnification or a magnification system may be used.

[0253]

Also, in the case of using a linear motor (refer to U.S. Pat. No. 5,623,853, or the U.S. Pat. No. 5,528,118) for the wafer stage or the reticle stage, either of the air levitation type using air bearings or the magnetic levitation type using the Lorentz force or the reactance force may be used.

[0254]

In addition, the stage may be a type that moves along a guide, or it may be a guideless type that does not require a guide.

[0255]

The reaction force generated by the movement of the wafer stage may be released to mechanically the floor (ground) using a frame member, as is disclosed, for example, in Japanese Patent Laid Open No. 08-166475 and the corresponding U.S. Pat. No. 5,528,118.

[0256]

And, the reaction force generated by the movement of the reticle stage may be released mechanically to the floor (ground) using a frame member, as is disclosed, for example, in Japanese Patent Laid Open No. 08-330224 and the corresponding U.S. Pat. No. 416558.

[0257]

The illumination optical system, the projection optical system PL, and the like which is made of a plurality of lenses are incorporated into the main body of the exposure apparatus to carry out optical adjustment, then the wafer stage system, the reticle stage system, and the like which is made up of various mechanical components are assembled into the main body of the exposure apparatus and the wiring and piping connected. The exposure apparatus in the embodiment of the invention can be fabricated by performing total adjustment (electrical adjustment, operational adjustment). Also, the exposure apparatus is preferably made in a clean room in which temperature, degree of cleanliness, and the like are controlled.

[0258]

The semiconductor device is provided through a step where function/performance is designed for a device, a step where a reticle based on the design step is fabricated, a step where a wafer is fabricated from silicone material, a step where reticle pattern is transferred to the wafer by the exposure apparatus of the embodiment described above, a step where devices is assembled (including dicing, bonding, and packaging), and checking step.

[0259]

Effects of the Invention

As the circumstances described above, according to an aerial image measurement method and an aerial image measurement unit of the invention, there is an effect to be capable of measuring an aerial image with a sufficient accuracy.

[0260]

According to an image forming properties measurement method of the invention, there is an excellent effect that can accurately measure the image forming properties of the projection optical system.

[0261]

According to an exposure apparatus of the invention, there is an effect to contribute to improving the exposure accuracy.

Brief Description of the Drawings

FIG. 1

FIG. 1 is a schematic view showing the arrangement of an exposure apparatus 100 related to the first embodiment according to the present invention;

FIG. 2

FIG. 2 is view showing an internal arrangement of the alignment microscope and the aerial image measurement unit in FIG. 1;

FIG. 3

FIG. 3 is a view showing a modified example of the aerial image measurement unit that has an arrangement of the optical sensor arranged external to the wafer stage;

FIG. 4

FIG. 4 is a view showing the state when the alignment microscope is detecting the alignment mark on the wafer;

FIG. 5

FIG. 5 is a view showing the state when the alignment microscope is detecting the slit of the aerial image measurement unit on baseline measurement by the alignment microscope;

FIG. 6

FIG. 6A is a planar view showing the aerial image measurement unit in a state when an aerial image PM' is formed on the slit plate on aerial image measurement;

FIG. 6B is a linear graph showing an example of the photodetection conversion signal (light intensity signal) P obtained upon the aerial image measurement;

FIG. 7

FIG. 7 is a linear graph showing the results of simulation at the best focus position, and shows the results of image forming simulation corresponding to the case when an aerial image of a L/S mark having a line width of 0.2 μm and a duty ratio of 50%;

FIG. 8

FIG. 8 is a linear graph showing the spatial frequency component when Fourier Transform is performed on the intensity signal P3 in FIG. 7, along with the original intensity signal P3;

FIG. 9

FIG. 9 is a linear graph showing the results of simulation at the position defocused by 0.2 μm from the best focus position;

FIG. 10

FIG. 10 is a linear graph showing the spatial frequency component when Fourier Transform is performed on the intensity signal P3 in FIG. 9, along with the original intensity signal P3;

FIG. 11

FIG. 11 is a linear graph showing the results of simulation at the position defocused by 0.3 μm from the best focus position;

FIG. 12

FIG. 12 is a linear graph showing the spatial frequency component when Fourier Transform is performed on the intensity signal P3 in FIG. 11, along with the original intensity signal P3;

FIG. 13

FIG. 13 is a planar view showing an example of a measurement reticle used on detection of the shape of the image plane;

FIG. 14

FIG. 14 is a planar view showing an example of a measurement reticle used on detection of the spherical aberration;

FIG. 15

FIG. 15 is a planar view showing an example of a measurement reticle used upon magnification and distortion measurement;

FIG. 16

FIG. 16 is a planar view showing an example of an aerial image measurement unit 59 used upon magnification and distortion measurement;

FIG. 17

FIG. 17 is a planar view showing the aerial image measurement unit in a state when an aerial image CMn' of the measurement pattern is formed on the slit plate upon aerial image measurement using a reticle on which measurement patterns consisting of a large L/S pattern are formed;

FIG. 18

FIG. 18 is a view showing an example of a mark block on which an artificial box pattern and other measurement patterns are formed;

FIG. 19

FIG. 19 is a view for explaining the first measurement method of coma aberration, and shows an example of a resist image;

FIG. 20

FIG. 20 is a planar view showing an example of a measurement reticle used in the first measurement method of coma aberration;

FIG. 21

FIG. 21 is a planar view showing the aerial image measurement unit when an aerial image EM' is formed on the slit plate in the case of using a combined mark pattern that has an arrangement of a plurality of L/S patterns with five lines combined in a predetermined period as each measurement mark;

FIG. 22

FIG. 22 is a view for explaining that the aerial image EM'; indicated in FIG. 21 has two fundamental frequency components;

FIG. 23

FIG. 23A is a planar view showing an example of a measurement reticle used in the second measurement method of coma aberration; FIG. 23B is an enlarged view showing a measurement pattern of FIG. 23A;

FIG. 24

FIG. 24 is a planar view showing the aerial image measurement unit when an aerial image GMn' of the measurement patterns consisting of a linear mark laterally symmetric that has a wide line pattern and a narrow line pattern arranged at a predetermined interval in the measurement direction is formed on the slit plate;

FIG. 25

FIG. 25 is a planar view showing the aerial image measurement unit when an aerial image HM' is formed of the measurement pattern indicated in FIG. 24 on the slit plate in the case when the linear marks are repeatedly arranged;

FIG. 26

FIG. 26 is a view showing measurement values of the contrast (the mark x) obtained at 13 points, when the slit plate is changed in the Z-axis direction in 13 stages (steps), with the horizontal axis as the Z-axis;

FIG. 27

FIG. 27 is a view showing measurement values of the amplitude of the first order component (the mark x) obtained at 13 points, when the slit plate is changed in the Z-axis direction in 13 stages (steps), with the horizontal axis as the Z-axis;

FIG. 28

FIG. 28A and FIG. 28B are graphs showing the S/N ratio related to focus detection in the case of applying the equation (6) when assuming an example of using a photo multiplier under the respective predetermined conditions;

FIG. 29

FIG. 29A and FIG. 29B are graphs showing the contrast respectively corresponding to FIG. 28A and FIG. 28B;

FIG. 30

FIG. 30A and FIG. 30B are graphs showing the first order respectively corresponding to FIG. 28A and FIG. 28B;

FIG. 31

FIG. 31A and FIG. 31B are graphs showing the S/N ratio related to focus detection in the case of applying the equation (8) under the same conditions as in FIG. 28A and FIG. 28B;

FIG. 32

FIG. 32A and FIG. 32B are views respectively showing the simulation data of the intensity signal of the light transmitting the slit, its differential signal, and the aerial image intensity, when the slit width is of equal magnification and is three times the minimum half-pitch;

FIG. 33

FIG. 33A and FIG. 33B are views respectively showing the simulation data of the intensity signal of the light transmitting the slit, its differential signal, and the aerial image intensity, when the slit width is five times the minimum half-pitch and is seven times the minimum half-pitch;

FIG. 34

FIG. 34 is a view showing the frequency characteristics when the slit width is equal, three times, and five times the half-pitch of the limit of resolution;

FIG. 35

FIG. 35 is a view showing an arrangement of an exposure apparatus related to the second embodiment of the present invention with a portion partly omitted;

FIG. 36

FIG. 36 is a view showing a state when the exposure apparatus in the second embodiment is using the aerial image measurement unit to measure the position of the laser beam spot upon baseline measurement with the alignment system ALG2;

FIG. 37

FIG. 37A and FIG. 37B are views for explaining other arrangement examples of the slit formed on the slit plate of the aerial image measurement unit, and the method of using the aerial image measurement units that have these slits formed; and

FIG. 38

FIG. 38A to FIG. 38C are views for explaining the conventional aerial image measurement method.

Description of Symbols

10 illumination system (illumination unit or a part of aerial image measurement unit)

20 main controller (controller, processing unit, or a part of aerial image measurement unit)

22a to 22d slit (a part of aerial image measurement unit)

24 optical sensor (photoelectric conversion device, a part of aerial image measurement unit)

90 slit plate (a part of aerial image measurement unit)

100 exposure apparatus

PL projection optical system

IL illumination light

R reticle (mask)

W wafer (substrate)

WST wafer stage (substrate stage)

ALG1, ALG2 alignment microscope (mark detection system)

FIG. 1

20 main controller

FIG. 6B

light intensity

FIG. 7

signal intensity

slit position

FIG. 8

signal intensity

slit position

FIG. 9

signal intensity

slit position

FIG. 10

signal intensity

slit position

FIG. 11

signal intensity

slit position

FIG. 12

signal intensity

slit position

FIG. 26

contrast

FIG. 27

first amplitude

FIG. 32A

signal intensity

slit position

FIG. 32B
signal intensity
slit position

FIG. 33A
signal intensity
slit position

FIG. 33B
signal intensity
slit position

FIG. 34
yield
frequency

FIG. 38B
signal intensity
opening position

FIG. 38C
differential value of signal intensity
opening position

Continued from front page

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G03F 7/02			G03F 7/22	H
H01L 21/027			H01L 21/30	525R

F term (Reference)	2F065	AA04 AA06AA07 CC20 DD04 EE08 FF01 GG04 HH06 HH13 LL01 LL28 LL63 MM24 PP12 QQ16 QQ23QQ41 UU01 UU02 UU05
	2G086	HH05 HH07
	5F046	BA03 DB05 DB08 FA09 FA16 FB14 FB16